SEDIMENTOLOGY, STRATIGRAPHY AND DIAGENETIC HISTORY OF THE TAGLU MEMBER AND EQUIVALENTS, MACKENZIE DELTA AREA, CANADA

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ABSTRACT

The Taglu is introduced as a new member of the Reindeer Formation. Its type section is in the Taglu G-33 well and its age is Eocene. This member conformably overlies the Aklak Member and underlies the "Un-named shale" or the "Kugmallit" member. The thickness of the Taglu varies from well to well but in the type section it is 800 ft. (268 m).

Correlation of the Taglu Member is difficult due to facies changes, similarity in composition of successive facies, faulting, and the absence of marker beds or diagnostic fauna. Correlation, however, was accomplished through seismic interpretation, sedimentary megacycles, trace elements, biology, gamma-ray logs and logic.

The Taglu Member was deposited under cool but occasionally warm temperate climatic conditions and is composed of two main deltaic sequences, each represented by a regressive phase overlain by a transgressive phase. Each sequence includes environments such as prodelta, delta front, distributary mouth bars, marshes and swamps, and finally distributary channels on top. The depositional basin during accumulation was undergoing moderate subsidence and receiving a high influx of sediments. Both the Richardson Mountains and the Eskimo Lakes Arch supplied, at least in part, the Taglu sediments. Occasional presence of volcanic rock fragments may indicate a third source, possibly well to the south.

Based on its composition, the Taglu sandstone can be classified as quartz arenite and sublitharenite. It consists of quartz, chert, feldspar, mica, rock fragments, woody herbaceous matter, and cementing material. The cementing material includes non-ferroan calcite, ferroan and non-ferroan dolomite, siderite, silica and authigenic clay minerals. The cement, which is mainly controlled by the environment of deposition, is eodiagenetic and in places mesodiagenetic.

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CERTIFICATE

I hereby certify that MONZER S. SHAWA has been engaged in research for 9 terms at the University of St. Andrews, that he has fulfilled the conditions of Ordinance No. 12 and Resolution of the University Court, 1967, No. 1, and that he is qualified to submit the accompanying thesis in application for the degree of Doctor of Philosophy.

I certify that the following thesis is of my own composition, that it is based on the results of research carried out by me, and that it has not previously been presented in application for a higher degree.

ACKNOWLEDGEMENT

I would like to acknowledge, with appreciation, the assistance and the stimulating discussion of Professor E.K. Walton of the University of St. Andrews and Dr. Henri Raasveldt of PetroCanada who both supervised the research and gave valuable advice and suggestions. The thesis was improved extensively by their critical reading.

I am greatly indebted to the management of Home Oil Company for their financial support. Thanks are also due to Mr. Richard Batchelor of the University of St. Andrews who preformed all of the Atomic Absorption and X-ray analyses.

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CHAPTER I

INTRODUCTION

The area of research is bounded by latitudes 68° 40' N and 69° 40' N, and longitudes 134° 00' W and 136° 23' W. It is located within the present Mackenzie Delta which is situated on the Arctic Coastal Plains of the Beaufort Sea in Northern Canada (Fig. 1). The topographic relief in the research area ranges from Sea Level to 825 ft. (250 m) reached in a spot in the Caribou Hills northwest of Inuvik (Fig. 2).

The present day Mackenzie Delta, which has a similar structural setting as the Taglu Delta, can be classified as a tidal delta being formed in a cold temperate climate. Its upper delta plain consists of many rejoining channels that have an irregular flow due to freezing in winter which periodically blocks the flow of water near Inuvik. Although tide action is low,it is amplified by the structural setting of the delta. Moreover, ice sheets may oscillate in early winter and produce swells similar to those of the tide action.

The Mackenzie Delta is bounded by the northward plunging Richardson Mountains on the west and the old Eskimo Lakes Arch Complex on the east and south (Fig. 2). This structural setting of the Delta has remained in its present location since early Tertiary time.

The Mackenzie Delta has been the site of extensive hydrocarbon exploration since July 9, 1965, when the Reindeer D-27 borehole

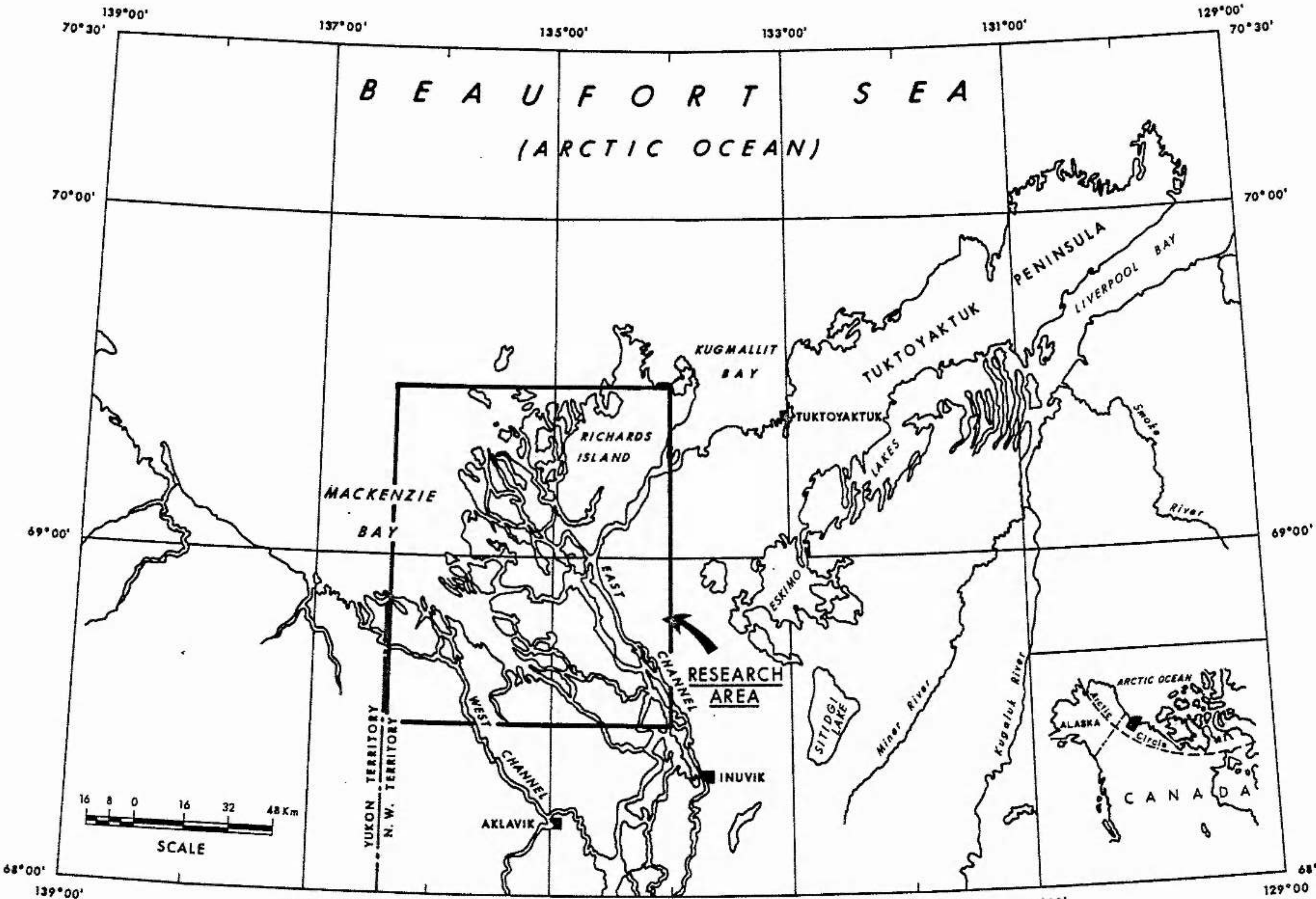
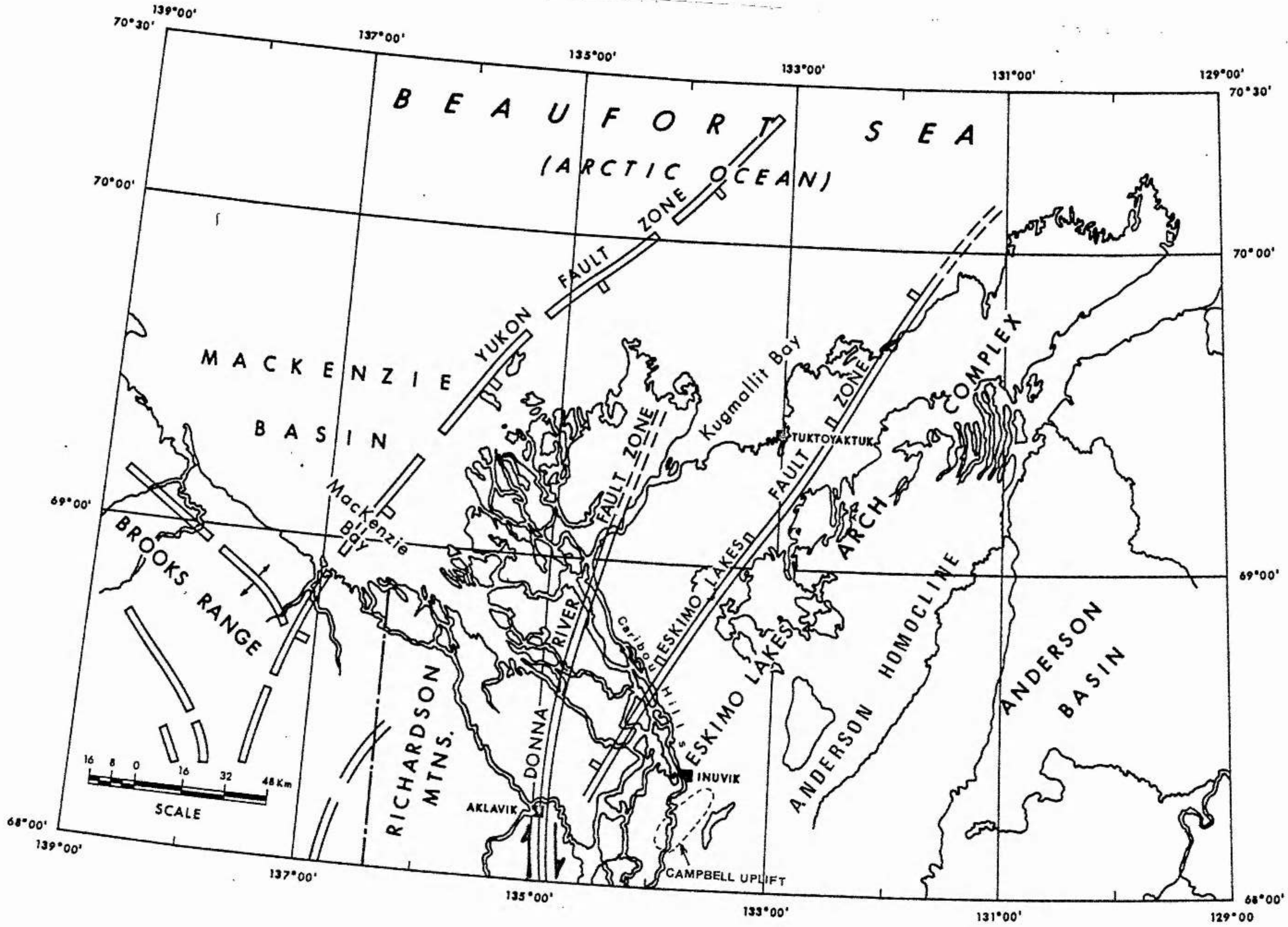


Figure 1 - Location Map



- Figure 2 - Major structural elements of Mackenzie Delta area.
Eastern faults are based on seismic interpretation.

was spudded on Richards Island (Fig. 5). The borehole raised exploratory interest because it proved the existence of a thick section of Tertiary deltaic and nearshore sediments overlying a Cretaceous marine sequence (Chamney, 1969), although no hydrocarbons were found in the borehole. June, 1971, saw the discovery of the Taglu Gas field. The discovery borehole, Taglu G-33 (Fig. 5), flowed gas at a rate of 28 mmcf/d from an Eocene sandstone interval at a depth of 8164 ft. to 8178 ft. (2488 m to 2492 m) near the top of the Taglu Member (new name) of the Reindeer Formation. Presently, the area of the Mackenzie Delta is estimated to have reserves in place of some 9 billion barrels of oil and 52 trillion cubic feet of gas (Bruce and Parker, 1975).

In late Maastrichtian time the North American epicontinental sea-way, which connected the Arctic Ocean with the Gulf of Mexico, shoaled and its waters receded to the north and south. The newly formed northern embayment was a site of sedimentary deposition and is now referred to, in part, as the Mackenzie Basin which occupies the southern part of the Beaufort Sea of the Arctic Ocean. Several Tertiary deltas were formed in space and time at the southern half of the Mackenzie Basin (Chamney, 1972; Shawa, et. al., 1974; Lerand, 1975; Young, 1975; and Young et. al., 1976). Some of these deltas coalesced to form continuous bodies of sand covering a large area of the wide continental shelf of the Beaufort Sea.

There is a lack of published sedimentologic studies on the Mackenzie Delta. Only a few suggestions have been made so far concerning a detailed depositional history of the Eocene Taglu Member. The lack of detailed work on such an important area in general and of an important horizon in particular made me decide to study the Taglu Member in detail. Thus the purpose of this research is to interpret the depositional systems within the Taglu Member and its equivalents, and to reconstruct the diagenetic history of the prolific hydrocarbon-bearing sandstone lithofacies.

Correlation of the Tertiary lithologic units in the Mackenzie Basin is difficult. Most previous attempts are based on micropaleontology including palynology with particularly the latter yielding good results. However, correlations based only on micropaleontology or palynology are still controversial due to the fact that a large number of forams, pollens and spores were reworked, in some cases more than one time. In this research project correlation is based on combinations of grain size, sedimentary cycles, palynology, gamma-ray logs, trace elements and seismic reflection profiles.

Methodology

The main sources of data are cores, both conventional and sidewall, and drill-cuttings from twenty nine wells drilled in the research area. The data are supplemented by several seismic reflection profiles. Unfortunately, not all cores are useful for two reasons: one, because the cores were cut at random depths and do not always include the Taglu Member, and two, because some cores, especially sidewall, were used up for micropaleontological analysis by the operators. Therefore, it was necessary to rely also on data derived from drill cuttings available for every well at 10 - foot (3.3 - meter) intervals. Special care was paid to obtaining representative samples in order to eliminate cuttings contaminated by recycling from shallower horizons.

A total of one hundred thin sections were prepared from conventional cores, sidewall cores and drill cuttings collected from sandstone of the Taglu Member and its equivalent horizons. The thin sections were prepared using the dry-grinding technique to prevent loss of authigenic clay minerals. Also 152 composite drill-cutting samples, each representing a 100 - foot (33 - meter) interval, were collected for X-ray fluorescence and atomic absorption tests for the identification of nine trace elements. Data obtained from thin sections supplied information on the texture, composition and diagenetic history of the Taglu Member lithofacies. Data obtained from trace elements were used to check correlations and to determine paleosalinity. Special emphasis was placed on detailed descriptions of sedimentary structures and their suites as observed in conventional cores. Lithologic descriptions were made of conventional cores, sidewall cores and drill cuttings, and the results were plotted on special forms. Sidewall and conventional cores constitute a low percent of the total examined samples. The thin sections that were prepared from these cores amounted to 38% . Appendix B lists the samples from which thin sections were prepared and Figure 5 shows the distribution of the control wells.

CHAPTER II

MEGATECTONICS

Structural History

Three major structural elements have defined the tectonic framework of Northern Canada since Precambrian time (Martin, 1961). These are: the North American Continental Craton (Canadian Shield), the Cordilleran Geosyncline which is located west of the Craton and the Franklinian Geosyncline (Fig. 3). The Mackenzie Basin, a tectonic depression, is situated in the southwestern flank of the Franklinian Geosyncline at the junction of the Craton and the Cordilleran Geosyncline.

An unusual continental drift hypothesis has been suggested by Tailleur and Brosgé (1970). They propose that rifting in the Arctic began in Early Jurassic at the time of the emplacement of mafic and ultramafic plutons in northern Alaska. They also suggested that rifting was followed by a major orogeny and scissor-like rotational drift in Early Cretaceous with a pivot point somewhere in the vicinity of Amundsen Gulf east of Liverpool Bay as shown in Figure 3.

On the other hand, Norris (1972) indicated that the Kaltag Fault of West Central Alaska, which has a right lateral movement, and which has been active since Cretaceous time (Patton and Hoar, 1968), may extend northeastward into Canada along the south flank of the Brooks Range, merge with the Yukon Fault zone (Fig. 2) and ultimately join the Nansen Fracture Zone (see a physical map of the Arctic) flanking the western limit of the Arctic Islands. This major fault may be the limit of the ancestral North American

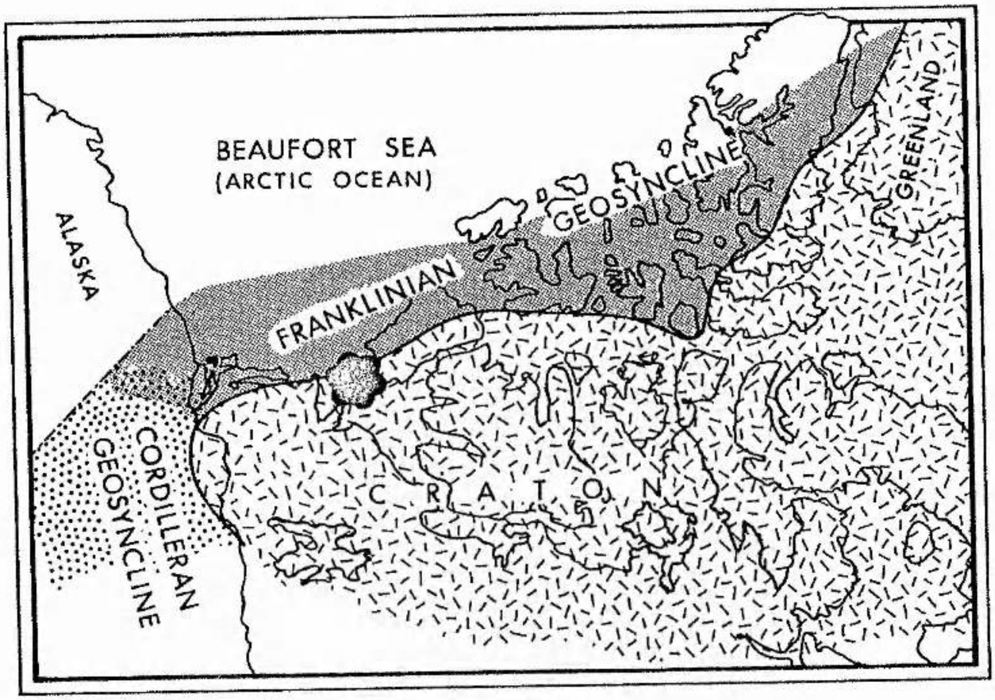


Figure 3 - Tectonic framework of Northern Canada (after Martin, 1961). Star shows approximate pivot point of rotational drift.

continental plate; if this is so, then part of Alaska and of Yukon Territory northwest of the fault is a part of the Eurasian plate. The fact that the geological trends of Alaska match those of the northern part of the U.S.S.R. for both the Cenozoic and Paleozoic eras lends support to this hypothesis (Norris, 1972).

Henri Raasveldt (personal communication, 1976) connects the Nansen Fracture Zone with the Donna River Fault Zone which follows the old, Paleozoic and possibly Prepaleozoic boundary between the Canadian Shield and the Yukon - Alaskan plate encased between the Arctic and Pacific oceans. This boundary was a zone of crustal weakness: a deep narrow basin filled with graptolitic, calcareous or cherty shales separating the carbonates of the Mackenzie Platform (nose of the Canadian Shield) from those of the Yukon Platform. This zone of weakness was upfolded (Mackenzie Mountains, Northwest Territories) and faulted (Nansen Fracture - Donna River Fault Zone) in late Mesozoic to mid Tertiary times.

The first two hypotheses do not affect the research area since no uplift or subsidence are suggested. The third hypothesis, however, might have an appreciable influence on the interpretation of sedimentation of the Taglu Member.

Regional Structural Framework

Eocene deformation during the Laramide Orogeny resulted in folding and uplift of the Richardson Mountains south of the research area. The tectonic elements of the Mackenzie Delta controlled the sedimentation during Eocene time. Almost all of the tectonic elements that were present during Tertiary time persist in the region today. These elements are the Eskimo Lakes

Arch Complex to the east and southeast of the Mackenzie Delta, the Richardson Mountains uplift to the south, and the Brooks Range (Romanzoff uplift) to the west (Fig. 2). The Eskimo Lakes Arch is a narrow structure with a Cretaceous core trending NE-SW. It is a tectonic component of the Aklavik Arch Complex which comprises the Dave Lord Arch, Rat Uplift, Cache Creek Uplift, Campbell Uplift; all trending in a roughly northeasterly direction and terminating in the Eskimo Lakes Arch which is the only element of this complex present in the research area.

The Eskimo Lakes Arch is flanked by the Anderson Homocline and Basin to the east and by the Eskimo Lakes Arch and Donna River Fault Zones to the west. Associated with it is the Caribou High, just east of Caribou Hills (Fig. 2), which is early Laramide (Young _et_. _al_., 1976) and is topped by Tertiary sediments of the Reindeer Formation. The axis of the Arch plunges northeastwards under the Tuktoyaktuk peninsula as indicated by strata observed on seismic profiles. North and west of the Eskimo Lakes Fault Zone the sedimentary section thickens rapidly towards and under the Beaufort Sea. Gravity maps show two major negative anomalies, indicating a great thickness of sediments, one under the Kugmallit Bay and the other under the Mackenzie Bay (Fig. 4). The two anomalies are separated by a positive anomaly.

In the research area the structure of the Mackenzie Delta is characterized by a series of folds, some roll-over, and faults trending northwest - southeast subparallel to the structural elements of northern Alaska and nearly perpendicular to the Donna River Fault zone (Fig. 5). In some cases the folds are bounded on one or both sides by small faults subparallel to their axis as can be seen on confidential

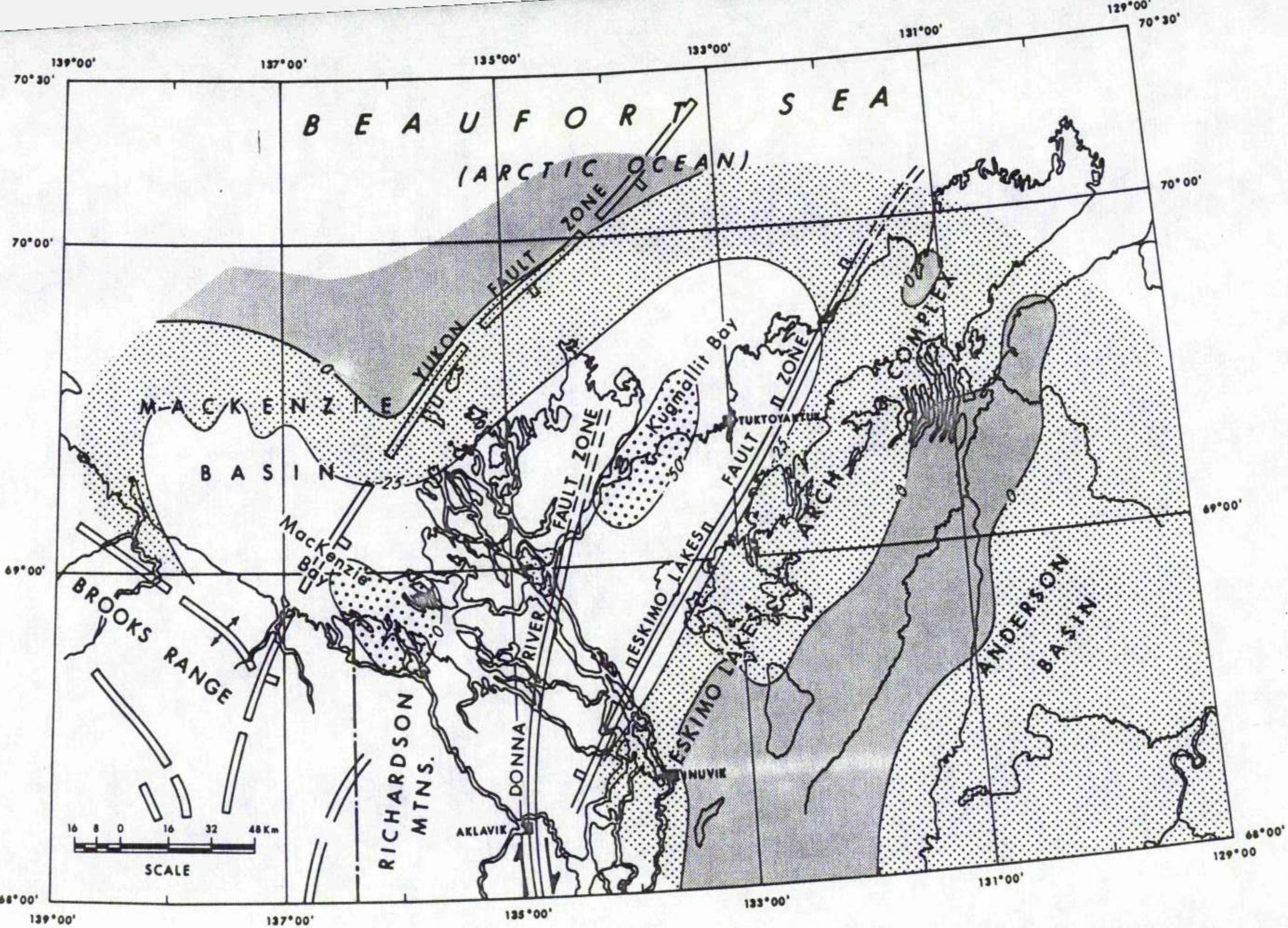


Figure 4 - Bouger gravity map of Mackenzie Basin. Contour interval 25 Gal.

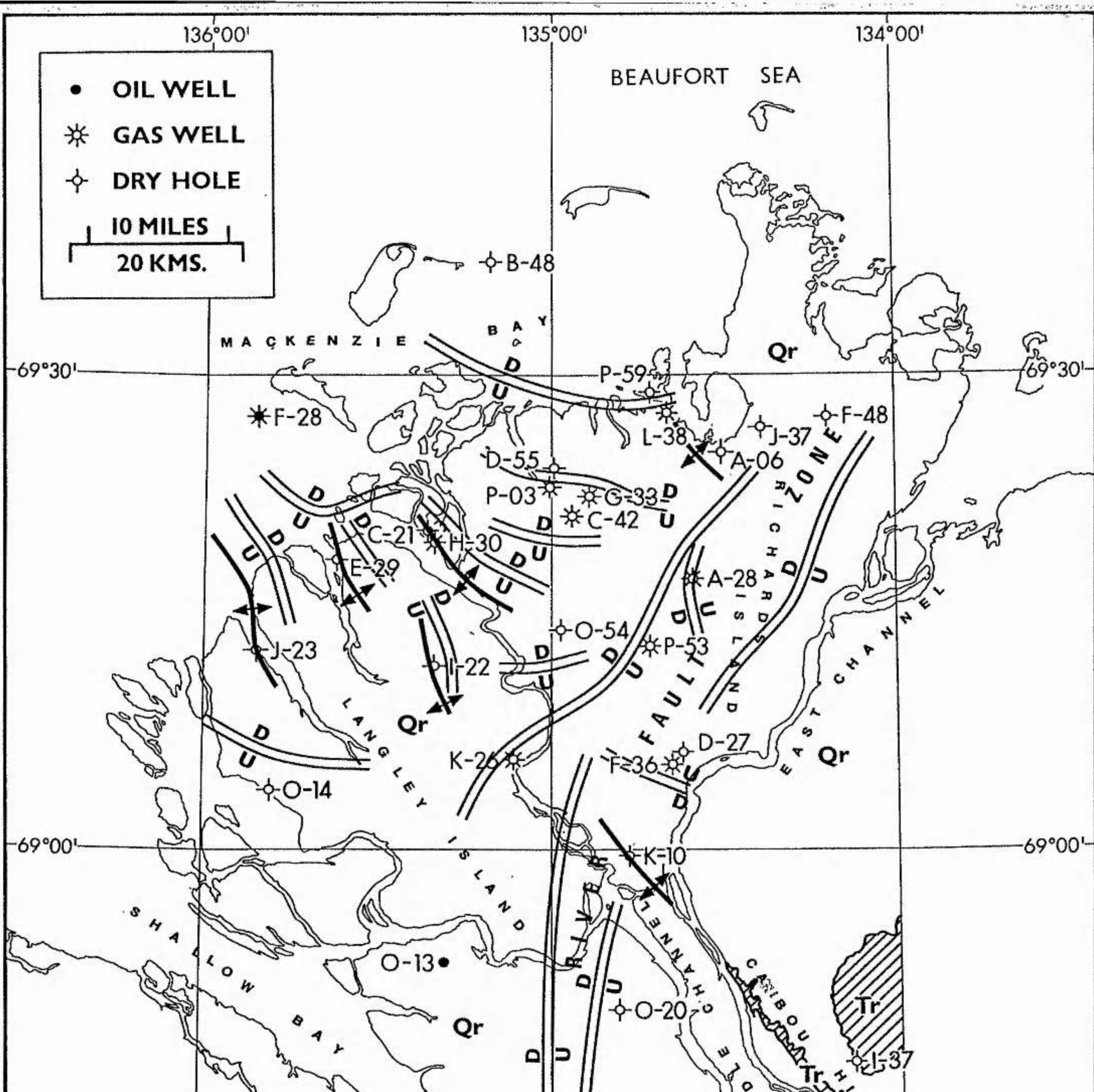


Figure 5 - Map showing location of boreholes, faults, folds (anticlines), and surface distribution of the Reindeer Formation.-

seismic maps prepared by some oil companies. Other types of structures observed on seismic records are mud diapirs present in the Mackenzie Basin where the Tertiary section becomes thicker.

All local faults in the Mackenzie area as well as those of the Eskimo Lakes Fault Zone are normal. At the surface and in the Mackenzie Mountains, south of Figure 5, the Donna River fault zone is regarded by oil company geologists as a strike-slip fault with considerable vertical downthrown of the west flank (D.K. Norris, 1975, G.S.C. Open File 302). Further northward in the subsurface underneath the alluvium of the Mackenzie River, in the vicinity of Kugmallit Bay (Fig. 4), confidential seismic sections reveal a reversal of the vertical movement but still further northward, north of Tuktoyaktuk peninsula (Fig. 1), no vertical movement is indicated by seismic profiles for the Tertiary section.

The Yukon fault zone discussed before has little bearing on this research area as it enters the area in the extreme north-westerly corner. It is believed that the Yukon Fault Zone was inactive during Tertiary time. Its presence underneath the Beaufort Sea is speculative.

During Mesozoic time some of the above mentioned tectonic elements such as the Eskimo Lakes Arch and the Richardson Mountains serves as source areas, contributed to the sedimentation and controlled its distribution in the Beaufort Sea. Young et. al. (1976) subdivided the Mesozoic sequence into three main tectono-sedimentary phases. They include a Late Triassic to early Aptian epicontinental sequence, the Late Aptian to Early Campanian flyschoid sequence, and the Late Campanian to Paleogene molassic sequence. Each, according to Young et. al., is characterized by its facies association, thickness variability and sandstone petrography. The Taglu Member directly overlies the Young _et_. _al_. sequences.

In Late Laramide time the Eskimo Lakes Fault zone was activated or possibly rejuvenated as indicated by Cote _et_. _al_. (1975) and a closely spaced step-like terrace, downfaulted toward the northwest, formed the southeastern flank of a basin underlying the western part of Tuktoyaktuk Peninsula and referred to as Kugmallit Trough by Young _et_. _al_. (1976). These faulted terraces can be detected clearly on seismic profiles. The basin or Kugmallit Trough existed during Tertiary time as indicated by boreholes and supported by seismic evidence. During Lower Cretaceous time this basin was not developed or it may have been located further northwest. This is supported by the fact that boreholes drilled just west of the above mentioned downfaulted terrace had penetrated to the Parson Sandstone, Lower Cretaceous, which was deposited in fluvial and nearshore environments.

Regional Geologic Setting

During the Paleozoic and the Mesozoic the Mackenzie Basin formed part of or was adjacent to the North American Cordilleran geosyncline which extended along the present-day Rocky Mountain southward into the United States of America (Lerand, 1975). The bulk of Jurassic and Lower Cretaceous sediments, most likely, came from the previously mentioned components of the Aklavik Arch Complex. In Late Cretaceous time the Brooks Range was an important source of sediments (Lerand, 1975) (Fig. 2). At that time the Mackenzie Delta area was submerged under marine water except for the Eskimo Lakes Arch Complex. Deposition of the marine shale of the Upper Cretaceous Fish River Group was extensive as indicated by its occurence in most of the boreholes examined in the area as suggested by seismic interpretation.

In Tertiary time a large embayment, a remnant of the Late Cretaceous waterway that connected the Beaufort Sea with the Gulf of Mexico, formed the northwestern continuation of what probably has been interpreted as a land locked water body near Norman Wells in which Early Tertiary sediments were deposited (Raasveldt, personal communication, 1977). As the entire area was uplifted during the Laramide Orogeny this land locked basin became eroded and early Tertiary sediments were redeposited progressively further north. The regional uplift of the Richardson Mountains, Eskimo Lakes Arch Complex and the area near Norman Wells announced the beginning of a major regressive phase that started in Paleocene time. The Taglu Member was deposited during the latter part of this major regressive phase. The Taglu area subsided in Eocene and a transgressive phase followed depositing an extensive shale unit over the entire area of the Mackenzie Delta. The shale unit is referred to by some workers as the "Unnamed shale". Another regressive sequence followed, possibly around Miocene time to deposit a sandstone and conglomerate sequence thicker than the first one and present mainly in the offshore area of the Beaufort Sea (Lerand, personal communication, 1976).

Young _et_. _al_. (1976) recognized three clastic wedges in the Delta area. The oldest comprises most of the Cretaceous Fish River Group (Tent Island and Moose Channel formations), on top of it is the Ministicoog Member of the Moose Channel Formation, and the Reindeer Formation. The third wedge, the youngest, consists of the "unnamed shale" and the overlying Unnamed Paleogene fluviodeltaic unit. These clastic wedges will be discussed in more detail in Chapter three.

CHAPTER III

STRATIGRAPHY

The stratigraphy of the subsurface of the Mackenzie Delta is based on the outcrops in two distinct areas on either side of the Mackenzie River and its distributaries. The main stratigraphic units outcrop on the northern side of the Richardson Mountains along the Big Fish River (called Fish River on old maps) and the Little Fish River (called Cache Creek on older maps) situated outside the southwestern corner of the research area. Complementary outcrops are found at the southeastern margin of the research area along the Caribou Hills (Fig. 5).

The Tertiary overlies disconformably Upper Cretaceous strata in the Mackenzie Delta south of the research area. This can be derived from surface geology and from seismic profiles of the subsurface. An exception to this disconformable relationship is where local unconformities exist on top of depositional highs of pre-Tertiary age. Such unconformities can be interpreted from seismic profiles. Upper Cretaceous, in turn overlies Lower Cretaceous unconformably and an angular unconformity is present in several outcrops in the Richardson Mountains, Campbell Uplift (Fig. 2), and locally in the subsurface.

The Upper Cretaceous in the Mackenzie Delta area consists of the Boundary Creek Formation and the Fish River Group. The Boundary Creek Formation is Campanian and possibly Cenomanian (Young, 1975). In places the Fish River Group, named by Young (1975), overlies disconformably the Boundary Creek Formation, and it is Campanian and Maastrichtian. Overlying the Fish River Group, conformably and unconformably in some localities, is the

Reindeer Formation which is Paleocene and Eocene (Mountjoy, 1967; Young et. al.,1976; and Lerand, 1975) and possibly younger.

Fish River Group

The Fish River Group derives its name from the Big Fish River where it is almost completely exposed along its banks. In its type section the group consists of approximately 6000 ft. (1830 m) of shale, sandstone, and conglomerate. It is divided into two formations; the Tent Island and the Moose Channel (Fig. 6).

Tent Island Formation: The Tent Island Formation comprises the lower part of the Fish River Group. It was referred to previously as the "Upper Cretaceous unnamed shale unit","Units 1 and 2", and "Upper Cretaceous shale division" by many workers. The formation was formally named by Young (1975) who assigned a type section for it along the northwest bank of the Big Fish River near its junction with the Little Fish River southwest of the research area. The Tent Island Formation overlies the Boundary Creek Formation unconformably in the Richardson Mountains and conformably in the subsurface. The latter relationship is interpreted from seismic profiles. The formation is overlain unconformably by the Moose Channel Formation, and it is Maastrichtian in age.

The Tent Island Formation was subdivided by Young (1975) into two members, the lower he formally called Cuesta Creek and the upper he informally referred to as the "Mudstone member".

Cuesta Creek Member: This member, apparently has limited lateral extent and it cannot be recognized in the subsurface. Its lower contact is unconformable with the underlying Boundary

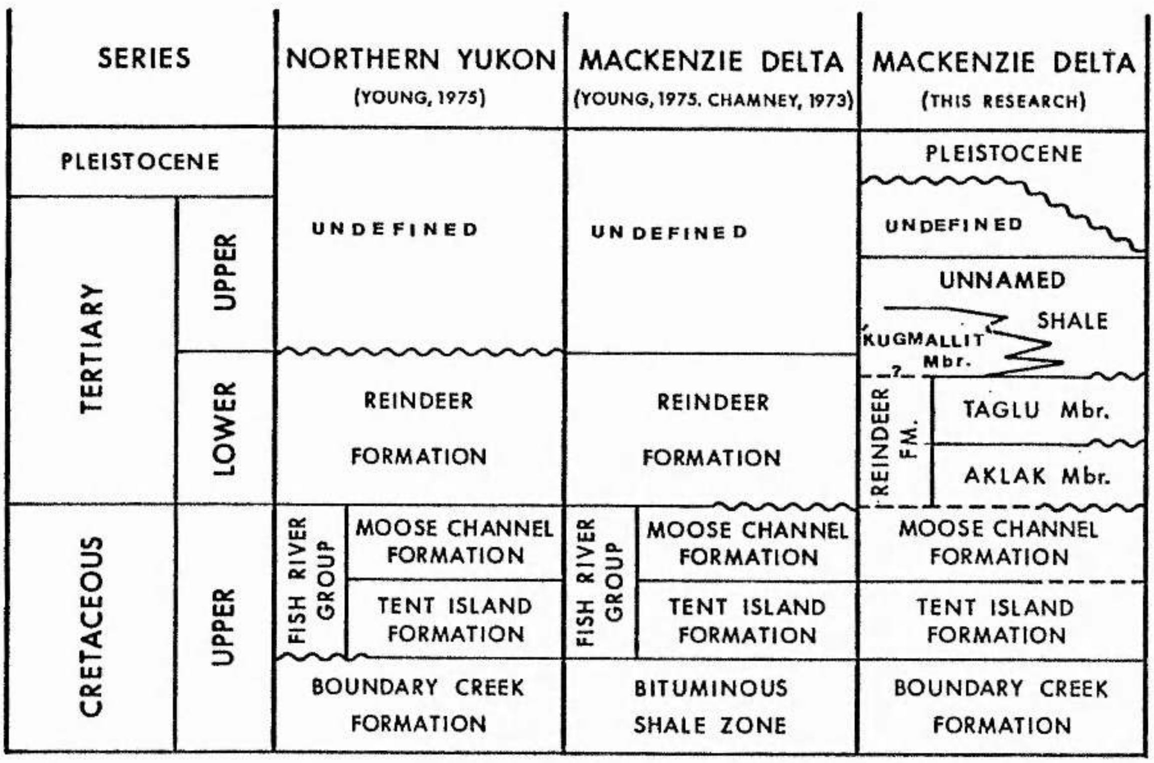


Figure 6 - Correlation table of Upper Cretaceous and Tertiary formations, Mackenzie Delta area.

Creek Formation and its upper contact varies from distinct to gradational.

The Cuesta Creek Member consists of dark gray, cherty sandstone, conglomerate that is either friable or consolidated; dark gray shale, and some thin coal seams. The cherty sandstone weathers reddish and orange. The shale is carbonaceous, limy and concretionary in places.

Mudstone member: Its thickness varies from about 2800 ft. (853 m) (Young, 1975) at the type section along Big Fish River to nearly 3700 ft. (1128 m) in the Reindeer D-27 borehole (Chamney, 1972) which spudded in Tertiary. In this borehole the Cuesta Member is absent (Young, 1975). The lower contact can be sharp or gradational and therefore it can not be determined precisely in all localities. In its lower part and near the base, the Mudstone Member of the type section contains sandstones, siltstones and pebbly mudstone intervals. The pebbly mudstones are graded and interbedded with laminated mudstone horizons. The upper part of the member which approximately constitutes the upper half, consists of light gray shale and mudstone.

In the Reindeer D-27 (Fig. 5) borehole the Mudstone member comprises the entire Tent Island Formation according to Young (1975). Here the Mudstone member consists of gray and brown gray shale, brown gray thin beds of fine-grained dolomitic, sandstone and siltstone in cyclic intervals. Occasional thin beds of conglomerate are also present.

Moose Channel Formation: The name Moose Channel Formation was given by Mountjoy (1967) to a sequence of about 1200 ft. (365 m) of non-marine, loosely consolidated sandstones exposed along the coast of the Mackenzie Bay and restricted to a belt about 10 miles

(16 km) wide on both sides of the mouth of Fish River southwest of the research area. Without detailed measurement or description Mountjoy designated the exposures near the mouth of Fish River as the type section of the Moose Channel Formation. Young (1975) measured the Moose Channel Formation at its type section and reported a thickness of approximately 3000 ft. (915 m). He also found that the formation crops out at locations other than previously thought. Mountjoy's definition of the Moose Channel Formation included in its upper part beds of sandstones, siltstone, and shale, rich in coal beds exposed along the banks of Aklak Creek southwest of the research area. Young (1975) took this sequence out of the Moose Channel Formation, placed it in the overlying coal bearing Reindeer Formation, thus speaking of the Aklak Member of the Reindeer Formation.

Young (1975) subdivided the Moose Channel Formation into two members, the informal "Basal sandstone" member and the overlying Ministicoog member which both are of Maastrichtian age.

"Basal sandstone" member: This member consists mainly of well consolidated, medium-grained sandstone, that contains pebbly horizons, which forms resistant ridges and is cut by steep-walled gorges. Along the Big Fish River it is approximately 1900 ft. (580 m) thick (Young, 1975) and thins to 1250 ft. (380 m) on Eagle Creek several miles to the northwest. In the subsurface the "Basal sandstone" member attains a thickness of about 2375 ft. (725 m) in Ellice O-14 borehole (Fig. 5) and about 1200 ft. (365 m) in Reindeer D-27. Young (1975) believed the member was deposited in a fluvial environment associated with deltas in subsiding basin.

Ministicoog Member: This member consists of gray mudstone siltstone and shale with minor coal. Its type section is located toward the mouth of the Big Fish River where it attains an approximate thickness of 1200 ft. (365 m). Its lower contact is gradational both at the surface and in the subsurface. Both the "Basal sandstone" and the Ministicoog members are eroded over the Eskimo Lakes Arch to the east and northeast. The upper contact is abrupt and marked by a distinct change in lithology from fine to coarse terrigenous material. In the type section along Eagle and Aklak creeks the upper contact is conformable, but in some places in the subsurface of the research area the Ministicoog Members show an unconformable relationship with the overlying Aklak Member.

<u>Reindeer Formation</u>: The Reindeer Formation was named by Mountjoy (1967) to indicate poorly consolidated sediments exposed in the Caribou Hills along the eastern bank of the East Channel in the southeastern corner of the research area (Fig. 5). This stratigraphic section was first measured and described by O'Neil (1915, 1924). He measured over 530 ft. (162 m) of loosely consolidated sediments about two miles northwest of Reindeer Depot. G.R. Turnquist (1962; <u>in</u> Mountjoy, 1967) measured, for the Geological Survey of Canada, two sections of the exposed sequence in Caribou Hills, one about 4 1/2 miles (7 km) northwest of Reindeer Depot and the other about 4 miles (6.5 km) southeast of it. Mountjoy's definition of the Reindeer Formation was premature. He did not define the full formation nor did he describe it in detail. The sections he referred to constitute a small part of the sequence exposed in the Caribou Hills.

The strata in the Caribou Hills dip 4° to the northwest and attain a thickness of approximately 4000 ft. (1220 m) (Young <u>et</u>.

al., 1976) which are all assigned to the Reindeer Formation. In the type section defined by Mountjoy the Reindeer Formation overlies unconformably Upper Cretaceous strata. This contact relationship is also demonstrated in Ikhill I-37 borehole (Austin and Cumming, 1976) which is to the east of the Caribou Hills (Fig. 5). The thickness of the formation in this well is approximately 4200 ft. (1280 m) and lithologies encountered are similar to those exposed in the Hills.

Southwest of the research area and west of the West Channel; a sequence of rocks that contains sandstone, siltstone, shale and are rich in coal was included in the original description of the Moose Channel Formation. This sequence was referred to as the "coal bearing member" (Young, 1972) or unit 5 (Holmes and Oliver, 1973) of the Moose Channel Formation. It was also included in the Moose Channel Formation by Mountjoy (1967). As mentioned before Young (1975) excluded this sequence from Moose Channel Formation and formally named it the Aklak Member of the Reindeer Formation. In the subsurface the Reindeer Formation is overlain conformably and in places unconformably by the "Unnamed shale" or the "Unnamed Eocene shale" as referred to by Young et. al. (1976). The "Unnamed shale" is about 1600 ft. (488 km) thick in the Mackenzie Basin increasing considerably in a northwesterly direction as indicated on seismic profiles. Toward the Eskimo Lakes Arch Complex the "Unnamed shale" grades into a sequence of sandstone and some siltstone and shale. This latter sequence is referred to as the "Kugmallit" Member which could be equivalent, in part, to the Reindeer Formation (F.G. Young, personal communications, 1978).

The Reindeer Formation in the subsurface is subdivided into two members, the lower one is the Aklak overlain by the Taglu. The Taglu is a new name introduced in this research (Fig. 6). In the type section the formation contains indigenous Paleocene pollen and spores which are younger than the palynomorph assemblages from the type Aklak Member (Young, 1975). The typical Reindeer Formation is Paleocene or probably Eocene according to G.E. Rouse (GSC Report F1-2-1965 - DCM) who collected samples from a locality about 3.5 miles (5.5 km) southeast of Reindeer Depot which yielded pollen and spores. Rouse, after later examination concluded that the sediments are most likely Paleocene rather than Eocene. In Ikhill I-37 the interval comprising the Reindeer Formation was assigned to the Paleocene and Early Eocene by Austin and Cumming (1977). But in the northern end of the Hills, the upper beds of the Reindeer Formation are assigned to the Oligocene according to Art Sweet of the Geological Survey of Canada (personal communications, 1977).

Aklak Member: The interval comprising the Aklak Member was studied at several localities west of the Mackenzie Delta by Young (1975); Mountjoy (1967); and Holmes and Oliver (1973). Its type section is on the Aklak Creek which flows into the southern end of Coal Mine Lake, southwest of Shallow Bay. The basal contact of the Aklak Member is distinct in all sections west of the Mackenzie Delta and is conformable in the subsurface in the Mackenzie Basin as demonstrated in Ellice O-14 borehole. East of the Delta, in the eastern side of the Mackenzie Basin and closer to the Eskimo Lakes Arch, the contact is an angular discordance in the Reindeer D-27 borehole (Young, 1975). The upper contact of the member is eroded in the type section and elsewhere on the surface, but in the subsurface it is conformable and gradational with the Taglu Member. Young (1975) defined its upper limit by changes in facies from predominantly non-marine to predominantly marine. But further in the basin the upper Aklak becomes marine as indicated by the presence of microfauna.

In the surface southwest of Shallow Bay and in the type locality the Aklak Member consists of sandstone, conglomerate, siltstone, shale and coal. The sandstone is light to dark gray, medium to coarse-grained, friable but well consolidated in places, thick bedded and pebbly, exhibiting northeast dipping tabular cross-beds. It becomes thin bedded and fine grained on top. The sandstones of the Aklak are lighter and more speckled than those of the Moose Channel Formation. The feldspar content is about 9% or less which is about half that of the Moose Channel. The chert content, which is about 34% on average, is double that of Moose Channel Formation. Other dominant minerals in the Aklak sandstone are quartz which constitute 42%, lithic and volcanic rock fragments 12%, plagioclase 2%, orthoclase 7%, according to Young (1975). The conglomerate is poorly sorted and has a coarse sandy matrix. The pebbles are composed mainly of chert and quartzite. The siltstone is brown gray, quartzose, it contains brown specks, and some cross-beds. The shale is dark gray, carbonaceous and silty. The coal is black, lignitic, hard and contains plant fragments. It was mined at Coal Mine Lake for many years. The Aklak shows a fining upward sequence. In the deeper part of the Mackenzie Basin in a northeasterly and northwesterly direction the Aklak Member becomes predominantly siltstone and shale.

In the Taglu G-33 borehole the uppermost part of Aklak consists of repeated cycles of shale, siltstone and sandstone. These cycles show a gradual upward increase in grain size and range in thickness from 50-180 ft. (15-55 m). They can also be seen on gamma-ray logs which show a gradual decrease in API values of radioactivity. The cycles are present in several boreholes and they serve as an excellent marker for the top of the Aklak Member.

Age: Several species of pollen, spores and plant fossils have been collected from the Aklak Member. W. A. Bell of the Geological Survey of Canada reported Trochodendroides (cercidiphyllum?) arctica (GSC locs. 6613-6615) which according to him is Paleocene. Mountjoy (1967) stated that D. C. McGregor examined spores and pollens in coal samples from the Aklak Member from a section at Moose River Mines on Coal Mine Lake. According to McGregor the spores and pollens suggest an age within the upper half of the Upper Cretaceous. W. W. Brideaux of the Geological Survey of Canada identified an assemblage of palynomorphs from a section near the base of the Aklak Member at its type section (GSC loc. C-11299): Stereisporites antiquasporites, sphagum (Stereisporites) regium, Inaperturopollenites hiatus, Laricoidites magnus, Sequoiapollenites paleocenicus Tristriopollenites sp. cf. T. costatus, Betulaceoipollenites sp. cf. B. infrequens and Triporopollenites sp. cf. T. rugatus. According to Brideau this assemblage suggests a Maastrichtian or early Paleocene age. A very similar assemblage was also collected from Ellice O-14 borehole at a depth of 4850 ft. (1478 m) (GSC loc. C-12661) recovered by Brideaux (1973). Brideaux (1973, GSC locs. C-12656 to C-12660) stated that samples collected from Ellice O-14 borehole from the depth interval 1160-5619 ft. (354-1710 m) contain an assemblage which suggests ages ranging up into the Eocene and possibly the Oligocene. This depth interval was considered by Young (1975) and Brideaux (1973) to represent the entire Aklak section in the well.

Based on the above, one can conclude that the age of the Aklak Member is Maastrichtian in the type section and surrounding area and Maastrichtian to early Paleocene in the subsurface in Ellice O-14 borehole.

Taglu Member: The Taglu Member is introduced here to refer to a certain sedimentary facies. Its type section is in the Taglu G-33 borehole. The member conformably overlies the Aklak Member and underlies the "Unnamed shale" and the "Kugmallit" member in the subsurface. It comprises an important gas producing interval of the Taglu Field. The lower contact of the member is taken at the base of a shale lithofacies present at a depth of 9022 ft. (2750 m) in Taglu G-33. This lithofacies overlies a sequence which consists of fine - to coarse-grained sandstone, siltstone, shale and coal beds included in the Aklak Member. The highest coal bed of this sequence occurs at a depth of 9690 ft. (2954 m). The lower contact of the Taglu is taken arbitrarily for convenience since the shale lithofacies is thick enough and recognizable in all of the Taglu Field boreholes. The upper contact is placed at the base of another thick shale unit at a depth of 8145 ft. (2483 m). This shale unit is recognizable over a large area in the Mackenzie Basin. It is known as the "Unnamed shale" or as Young et. al. (1976) referred to as the "Unnamed Eocene shale".

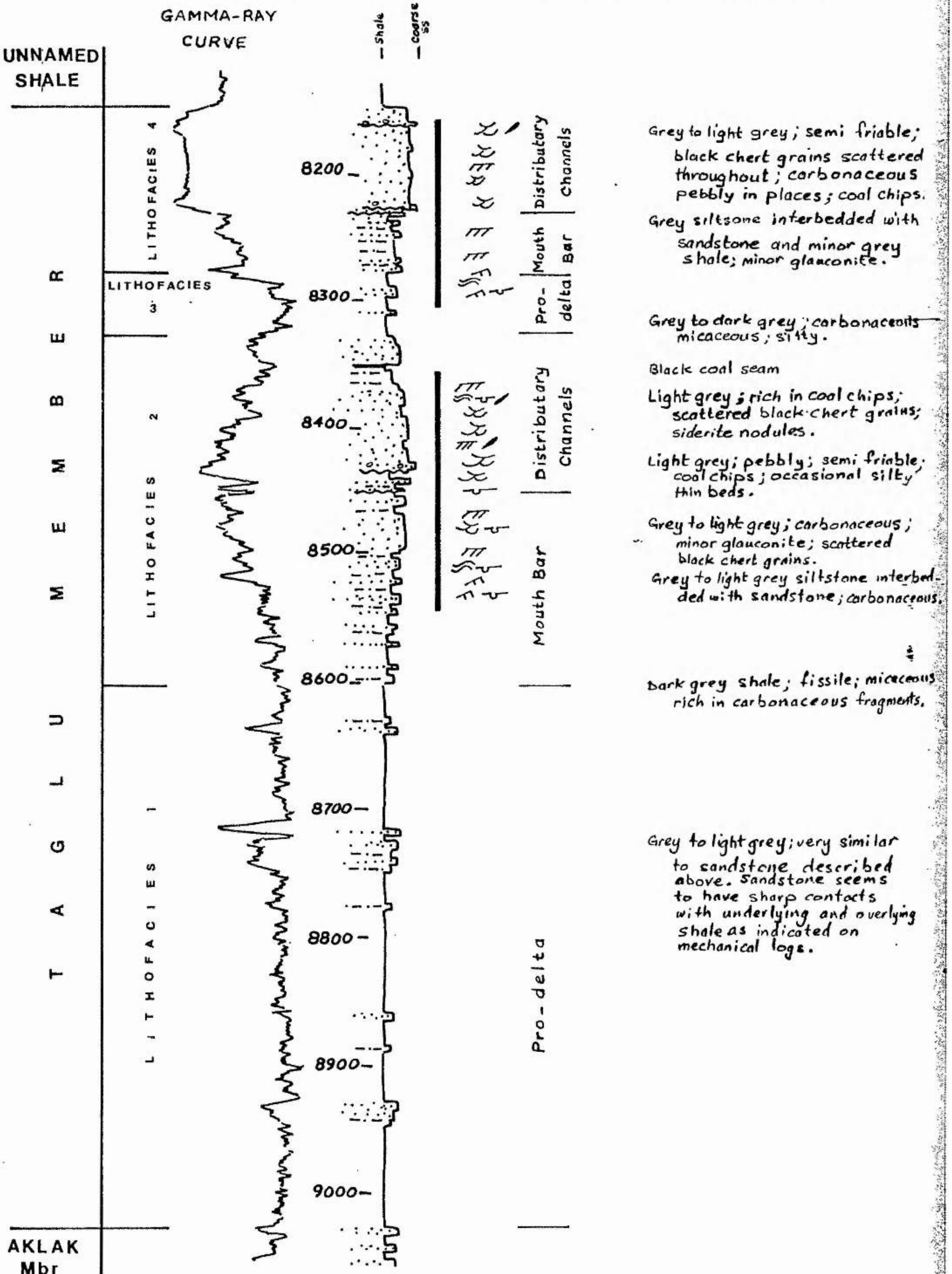
The "Unnamed shale" is widespread in the Mackenzie Basin and consists of marine mudstone, shale, minor bentonite, marlstone and muddy conglomeratic sandstone (Glaister and Hopkins, 1974). A clastic wedge ("Kugmallit" member) of medium - and coarse - grained sandstone overlies the Taglu Member in some boreholes in the southeastern part of the research area such as in the case in Reindeer D-27. Deeper in the basin the clastic wedge interfingers with the "Unnamed shale".

The Taglu Member can be subdivided, in the type section, into four lithofacies (Fig. 7). The lower one is a shale lithofacies1, overlain by a sandstone lithofacies2 which in turn is overlain by a thin, shaly lithofacies and finally a sandstone lithofacies on top4. The thickness of these units varies from one borehole to another but the four lithofacies are present in all boreholes of the Taglu Field and in some of the boreholes immediately south of the field.

The lower shale lithofacies attains a thickness of 425 ft. (130 m) and consists of light gray shale and silty shale. The shale is micaceous, fissile, and contains scattered sand grains which give it a sparkling appearance. Abundant carbonaceous fragments are scattered throughout the shale. Thin interbeds of very fine-grained sandstone, siltstone, and mudstone occur repeatedly throughout the unit. These sandstone interbeds are gray; slightly calcareous; rich in carbonaceous fragments and contain dark chert grains which give them a speckled appearance. The siltstone interbeds are shaly, gray to light gray, micaceous, contain carbonaceous fragments and scattered, very fine quartz grains.

The overlying sandstone lithofacies consists predominantly of gray sandstone, very fine - to medium-grained. It is sideritic,

Fig. 7– Stratigraphic Section Taglu G–33 (Taglu Type Section)
(for sedimentary structure symbol explanation see Figure 20)



pebbly in places, especially near the top, and slightly calcareous. It has a silty matrix and contains scattered coal chips, dark chert grains giving it a speckled appearance, and minor glauconite. The grains are moderately sorted. Very thin and minor bands of coal are present near the uppermost part of the unit. The sandstone is friable in places and consolidated in others. It exhibits several types of sedimentary structures such as vertical worm burrows, ripple marks, deformed structures, convolute laminations, planar and trough cross-bedding, and rip-up clasts (Plate 1). Siltstone beds are abundant in the lower part of this sandstone lithofacies. The siltstone is grey, argillaceous, contains scattered sand grains and carbonaceous fragments. It is also sideritic and slightly calcareous. The thickness of this sandstone lithofacies is 185 ft. (56 m).

The sandstone lithofacies is overlain by a thin dark grey shale lithofacies, which contains very thin stringers of very fine-grained sandstone, siltstone and shale. The stringers are very similar to those described in the underlying shale lithofacies. In the middle of the shaly lithofacies a fine-grained micaceous sandstone interval is present. The thickness of this thin shaly lithofacies is 50 ft. (15 m).

The thin shale lithofacies is overlain by a sandstone lithofacies, medium-to coarse-grained, moderately sorted, argillaceous and silty, and slightly sideritic. It contains dark chert grains, giving it a speckled appearance, coal chips and scattered carbonaceous fragments. Minor bands of very thin coal are also present. The sandstone is friable in some places and more consolidated in others. In its lower part the sandstone lithofacies contains several interbeds of brownish grey, shaly siltstone which

Plate I. Trough cross-beds on medium scale in very coarse-grained sandstone. A shale rip-up clast (a) near centre of photo. White patches are calcite cement. 1:1 scale, Taglu G-33 at 8222 ft. (2506 m) depth.

contains scattered very fine quartz grains, coal chips, carbonaceous fragments and glauconite. Shale is very rare, only two very thin dark gray beds are present in its lower part. The lithofacies exhibits a suite of sedimentary structures almost identical to the one found in the lower sandstone lithofacies. Its thickness is 180 ft. (55 m).

The Taglu Member in its type section consists of two sedimentary cyclothems. Both show gradational change in lithology from predominantly shale on bottom to predominantly siltstone and finally sandstone on top. This change in lithology also coincides with an upward increase in grain size and a general increase in bed thickness. The uppermost part of the lower cyclothem, however, shows a fining upward sequence from coarse to fine-grained sandstone (Fig. 7) and a decrease in bed thickness. In the uppermost part of the upper cyclothem only a slight upward decrease in grain size from coarse to medium is observed.

The Taglu Member is unidentifiable in the type section of the Reindeer Formation of Mountjoy. It is eroded in Ikhill I-37 borehole located 2.5 miles (4 km) east of the Caribou Hills as well as in Kipnik O-20 located nine miles (14 km) west of the Hills (Fig. 5) as based on seismic interpretation. It absence in these two wells is attributed to erosion.

The lithofacies of the Taglu Member become coarser in a southerly and easterly direction away from the type section. They also become finer and ultimately grade into siltstone and shale in northern and western directions.

The thickness of the Taglu Member varies from one place to another. In the type section in Taglu G-33 borehole it is 800 ft. (268 m), in Langley E-29 it is 820 ft. (250 m), in Adgo F-28 it is 545 ft. (166 m), and in Reindeer D-27 it is 500 ft. (152 m). It is eroded in Tununuk K-10, Kugpik O-13, Reindeer A-01, and Unak B-11 (Fig. 5).

There is a general lack of diagnostic microfauna in the subsurface part of Tertiary sediments of the Mackenzie Delta area. Most of the forms are reworked or poorly preserved. Pollens and spores are the most important forms that can be used in this area for age determination and correlation.

The marine dinoflagellate Wetzeliella hampdenensis is one of the most important marker fossil in the Mackenzie Delta area. It is reasonably widespread, and found in the lowermost part of the "Unnamed shale" just above the Taglu Member. Wetzeliella articulata also occurs together with W. hampdenensis (Staplin, 1976) and Astrocysta sp. Diagnostic terrestrial palynomorphs occur alone, within and just below the Taglu Member; these are: Pesavis tagluensis, Epiphyllous fungi, Azolla sp., Aquilapollenites cf. reticulates, Granatisporites sp., and G. cotalis. This fossil assemblage occurs in an interval that includes the Taglu Member in most of its parts. Austin and Cumming (1976) named the zone in which this assemblage of marine dinoflagellates and terrestrial palynomorphs occurs the Pesavis tagluensis Zone.

Age: The age of the Taglu Member is Eocene. This has been established from dinoflagellates and palynomorphs by Barnes et. al. (1974); Staplin (1976); and Shawa et. al. (1974). Austin and Cumming (1977, 1976) in detailed biostratigraphic reports assigned varying Eocene ages for the Pesavis tagluensis Zone in several boreholes. In Adgo F-28 they established a Middle Eocene, in Langley E-29, an Upper Eocene, in Ya Ya A-28 a Lower Eocene, in Taglu C-42 an Upper Eocene and in Niglintgak H-30 a Middle Eocene age.

CHAPTER IV

METHODS AND RESULTS OF CORRELATION

Correlation of the Taglu Member lithofacies in the Mackenzie Basin is difficult due to facies changes, similarity in composition and texture of successive facies, faulting and the absence of marker beds. Unfortunately biologic correlation has limited application due to the fact that many foraminifera and palynomorphs of the Tertiary are the product of reworking and the latter, moreover, are long ranging species. But before the environment of deposition and the diagenetic history are interpreted, the stratal continuity of the Taglu Member must be established in the boreholes. Therefore, correlation became a primary objective of this research. Knowledge of the location and trend of faults, location of geologic highs and lows, and the configuration of the basin as obtained from seismic and gravity data proved helpful in correlation.

The Tertiary section of the research area is very thick, therefore, the correlation had to proceed in two stages. One, a gross correlation applied to major cycles or thick sequences, was followed by a fine correlation of the lithofacies of the Taglu Member. Correlation was accomplished by considering all the physical, biological and chemical aspects of the rock. Physical correlation dealt with vertical sequences of facies, vertical distribution of the grain size, position of lithologic units or sequences and stratification. Biological correlation was based on key species and fossil assemblages contained in lithologic zones. Chemical correlation included the composition of the minerals that form the rock sequence. In this research trace elements were used. Some of these elements are inherited from the parent rocks and some were incorporated authigenetically in certain environments during deposition. Those inherited from the parent rock are useful in correlation and those reflecting authigenesis are helpful in interpreting the environment. Gross correlation techniques were used to determine the vertical and lateral extension of the Taglu Member within the research area. They are based on seismic profiles, major sedimentary cycles, gamma-ray and sonic logs, and biological data. The application of each of the above mentioned techniques is discussed in detail below.

Seismic Correlation

The technique is based on the principle that different lithologies have as a general rule different velocities (Russel, 1960). Therefore, when sandstone and shale units overlie one another their contacts serve as reflection surfaces which are recorded on seismic profiles. Under favourable conditions these reflections can be traced horizontally over a large area.

Seismic correlation proved difficult, because of the absence of good quality seismic records and profiles in many places. Physical conditions particularly at the surface of the Mackenzie Delta area, such as permafrost, the presence of buried ice wedges expressed at the surface by numerous pingos, and erratic Pleistocene and Holocene sedimentary cover inherited from severe glaciation, make this one of the most difficult areas to obtain good quality seismic records. To these surfacial complexities are added those in the subsurface. The presence of faults which terminate abruptly distorts the reflection which may make it difficult to pursue across the fault plane. Finally, changes in facies which can be quite abrupt in buried deltaic deposits (see Chapter VI) cause energy dispersals and changes in the characteristics of reflections and consequent loss of identity.

It has been assumed that seismic reflections are approximate ~~isochronous surfaces or~~ depositional surfaces. This assumption makes it possible to establish the sequence of stratigraphic units within a basin. Brown and Fisher (1976) stated that such units permit accurate stratigraphic correlations provided good quality seismic profiles are available. The Taglu Member constitutes one of these seismic stratigraphic units, although diachronous lithofacies changes must somewhat modify Brown and Fisher's assertion.

Establishing, in general fashion, the Mackenzie Basin framework as discussed in Chapter II and III, simplifies the correlation of seismic stratigraphic units. In spite of the inferior quality of seismic records it is felt that the regional correlation obtained from the seismic profiles was satisfactorily objective but that going into further detail would be highly subjective. Seismic profiles also supplied valuable information on the presence and trends of folds and faults in the subsurface in places where no borehole data are available (Fig. 5).

The seismic correlation of the Taglu Member is illustrated by two seismic cross-sections marked B-B' and C-C' and shown on Figures 8, 9. Other seismic profiles were used for this research and they supplied valuable complementary data on the areal distribution of the Taglu Member and on the structure. Unfortunately no permission to show them in this report was granted by the companies who own the ownership rights. The seismic profiles shown here pass through or adjacent to a large number of boreholes

(Fig. 10). Therefore, it was possible to compare the interpretation made on seismic profiles with the stratigraphic interpretation made in those boreholes and to adjust the two interpretations, provided borehole depths could be converted satisfactorily into seismic travel-time or vice versa.

In order to determine the approximate depth to a certain seismic reflection both the average velocity of the overlying strata and the travel-time of the sonic wave to that reflection must be known. This relationship is expressed in the simple mathematical equation, D=V.T; where D is the depth in ft., V is the average velocity in ft./sec., and T is time per second. T is recorded on the seismic profiles and V was calculated from sonic logs available for all of the boreholes in the research area in the following way: Velocity surveys giving the sonic travel-time as a function depth are very rare in the Mackenzie Delta, so that for the boreholes used in the seismic correlation this function had to be derived from the sonic logs. In some sonic logs the travel-time is integrated for each run by field computers during the survey appears as little ticks beside the footage scale, each tick representing a millisecond interval. The travel-time from the beginning till the end of the sonic survey is thus easily determined by a count of the ticks throughout the runs and thus only for the part of the borehole section above the start of the survey the travel-time needs to be estimated. This estimate is based on an evaluation of the rocks near the surface and even when this can be done sufficiently accurately, other factors such as transversed ice-wedges and the depth of the permafrost remain largely unknown so that the greatest errors in travel-time depth function are due to uncertainties near the surface. For boreholes lacking the ticks an average, straight line was drawn by eye through the undulating sonic curve of an appropriately chosen interval (D_1 feet). The average transit time for this interval can then be read on the sonic scale of the log (ΔT), and this value multiplied by D_1 yields the sonic transit time $D_1 \cdot \Delta T_1$, for the interval D_1. The same procedure was repeated for the next footage intervals D_2, D_3, etc. and the resulting transit time intervals $D_2 \cdot \Delta T_2$, $D_3 \cdot \Delta T_3$ correspond with the ticks discussed before, the only difference being that in this case the interval $D_1 \cdot \Delta T_1$, $D_2 \cdot \Delta T_2$, etc. are not equal duration. The transit time over the whole interval of the sonic log is then $\Delta T = D_1 \cdot \Delta T_1, \ldots D_n \cdot \Delta T_n$. The depth estimate which corresponds with sonic travel time was found to be accurate within 1000 ft. (305 m). That is to say that the depth of the Taglu Member can be located within 1000 ft. (305 m) interval in a borehole if that seismic profile goes through or runs adjacent to this borehole.

The seismic stratigraphic unit which represents the Taglu Member in Taglu G-33 borehole was determined on seismic cross-section C-C' (Fig. 9). The reflections of the seismic stratigraphic unit in the area of the Taglu G-33 show distinctly a basinward progradation of sedimentary units, marked in red, in a northerly direction. As stated before, the surfaces of the sedimentary units constitute approximately isochronous surfaces (Brown and Fisher, 1976). The seismic stratigraphic unit of the Taglu Member is overlain by another seismic stratigraphic unit which consists of very weak and interrupted short reflections. The latter unit represents the "Unnamed shale" which overlies the Taglu Member. Weak and interrupted reflections could indicate a repetition of thin beds of shale and sandstone. Only a reasonably thick bed of contrasting lithology will reflect the seismic waves.

The Taglu seismic stratigraphic unit was traced southwestward to the Ellice O-14 and northeastward to Mallik L-38 boreholes along seismic cross section C-C' (Fig. 9). In Mallik L-38 the unit is unidentifiable due to a change in facies from sandstone and shale to predominantly shale. In Taglu C-42 it is intersected at about 8750 ft. (2667 m) and in Unipkat I-22 it is at 750 ft. (229 m). In Ellice O-14 the unit was found at about 1500 ft. (357 m).

The Taglu seismic stratigraphic unit also shows distinct basinward progradation of sedimentary units in a northerly direction, as shown on seismic lines (not shown here) parallel to geologic cross section A-A (Fig. 10). In Reindeer D-27 the Taglu seismic unit is unidentifiable due to the absence of a thick contrasting lithology. In YaYa P-53 the unit is intersected at about 5200 ft. (1585 m). In Taglu P-03 it is found at about 9700 ft. (2956 m). Finally, the seismic stratigraphic unit disappears in a northwestward direction due to a change in facies to predominantly shale. The shale here attains high thickness which promotes mud diapirisim in the area as can be seen in the vicinity of Immerk B-48.

Seismic cross-section B-B' (Fig. 8) is of inferior quality therefore the Taglu seismic stratigraphic unit can not be identified and traced satisfactorily in several places. On the Eskimo Lakes Arch Complex the unit is eroded; this occurs also in both locations of Reindeer A-01 and Ikhill I-37. In Tununuk K-10 it is near the surface or it could be eroded. In Reindeer

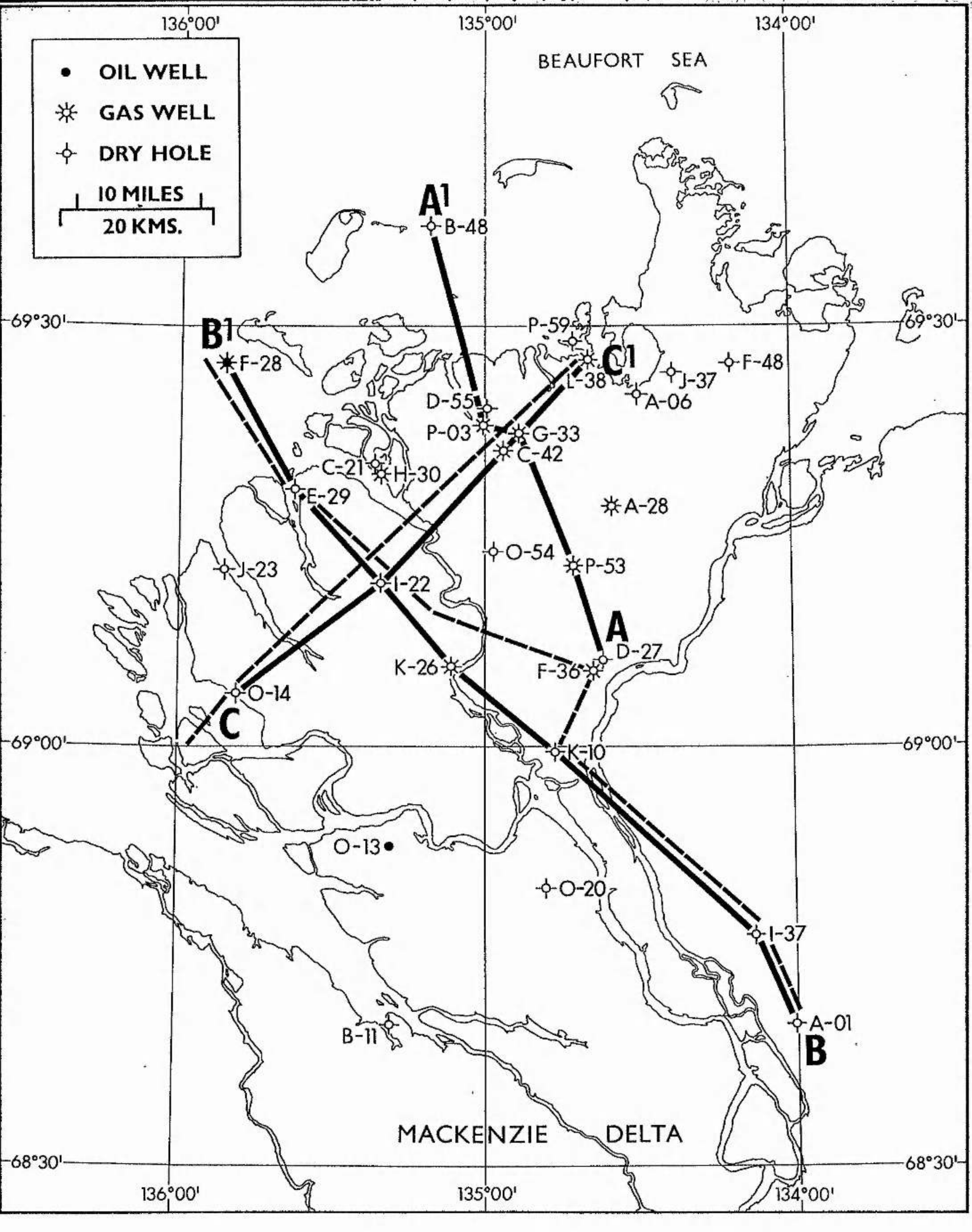


Fig. 10- Map showing location of boreholes, lines of seismic profiles and geologic cross sections.

D-27 it can be identified and in Langley E-29 it is intercepted at about 4200 ft. (1280). In Adgo F-28 the Taglu unit is unidentifiable due to poor quality of the seismic record. Although seismic cross-section B-B' is of poor quality it shows clearly the general attitude of the strata and the location of faults and folds.

Correlation of Major Sedimentary Cycle

This correlation was obtained through the use of diagrams presenting the grain-size and the radioactivity continuously throughout the sedimentary sections of many boreholes located along the geologic cross-sections A-A' B-B', and C-C' (Fig. 10). The diagrams derived from a technique developed by H.C. Raasveldt of PetroCanada and the author for the purpose of analysing and documenting the orogenic history of areas bordering depositional basins. The technique is planned for future publication but presently the following brief description will suffice.

The grain-size diagrams are derived from stratigraphic sections (logs) prepared by the Canadian Stratigraphic Service Ltd., Calgary, from drill cuttings. The grain-size value obtained from the logs was averaged for 100 ft. (30 m) intervals throughout the entire depth of each borehole and these averages were subsequently smoothed by a computer program. The diagram show the average grain-size plotted in grain-size units 0 (shale) to 6 (pebbles) as a function of depth (Fig. 11).

The gamma-ray diagrams are based preferably on the corresponding logs run down the borehole in conjunction with the sonic tool, which is a centrabred tool measuring the radioactivity in the center of the borehole, as opposed to the gamma ray-neutron

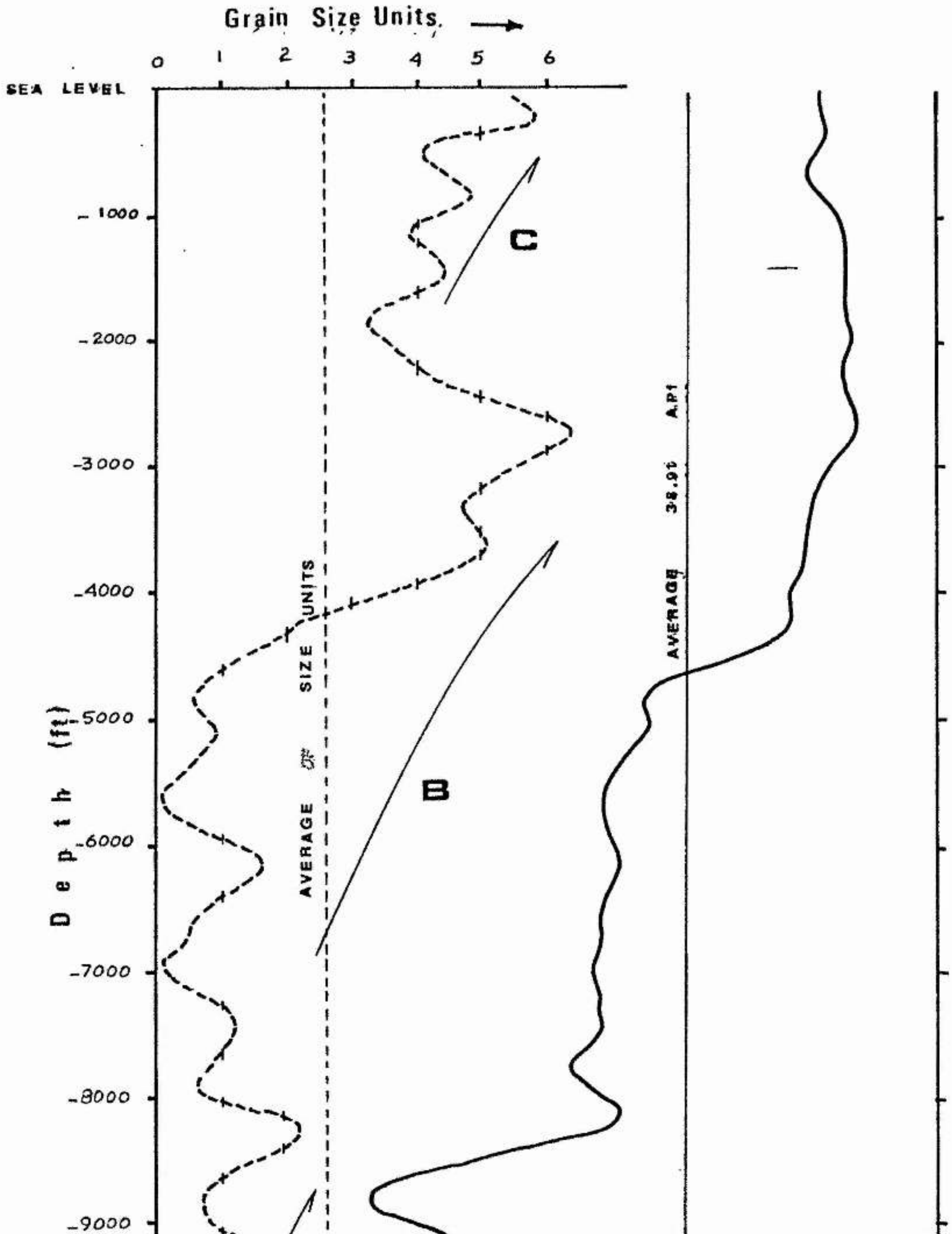


Figure 11 - Curves representing averages of grain-size and gamma-ray units of the rock sequence in Taglu G-33 borehole which shows three major sedimentary cycles; A,B,C. Lower API unit corresponds with coarser grain size. Grain-size units; 0= shale and silt, 1=very fine, 2=fine, 3=medium, 4=coarse, 5=granular and 6=pebbly.

survey where the tool is run excentrically, pressed against the wall of the borehole. Though the latter survey may better represent the radioactivity of the rocks, these surveys are less frequent, especially in older boreholes, and therefore they were only used in cases where gamma-ray tool combined with the sonic did not register properly. Only the roughest corrections were made at the switch from one tool to the other and at the change of diameter of the borehole. In view of the many troughs and peaks in the gamma-ray curve, averages were first made by eye across 10 ft. (3 m) intervals and from these data the 100 ft. (30 m) averages were subsequently computed. The 100 ft. (30 m) averages were then smoothed by the same computer program used for smoothing the grain-size curve. The obtained curve showing the average radio-activity as a function of depth (Fig. 11) is comparable to that of the grain-size.

In Taglu G-33 borehole average grain-size values suggest the presence of three major cycles; A, B, and C (Fig. 11). The lowermost one extends upward to about 8000 ft. (2438 m), the second to about 2000 ft. (610 m), and the third to the surface. Two of these cycles are suggested by the average gamma-ray values. But in the upper part of the borehole or cycle C, gamma-ray is not definitive. This is due to excessive sloughing of very loose gravel which increased the borehole diameter. The Taglu Member is present in the upper part of the first cycle or A.

Each major cycle represents a transgressive and regressive phase of sedimentation. Because of their appreciable thickness their lateral continuity is expected to be high. Therefore, they were used for gross correlation. Figures 12-14 show the lateral distribution of the three major cycles. The cycles

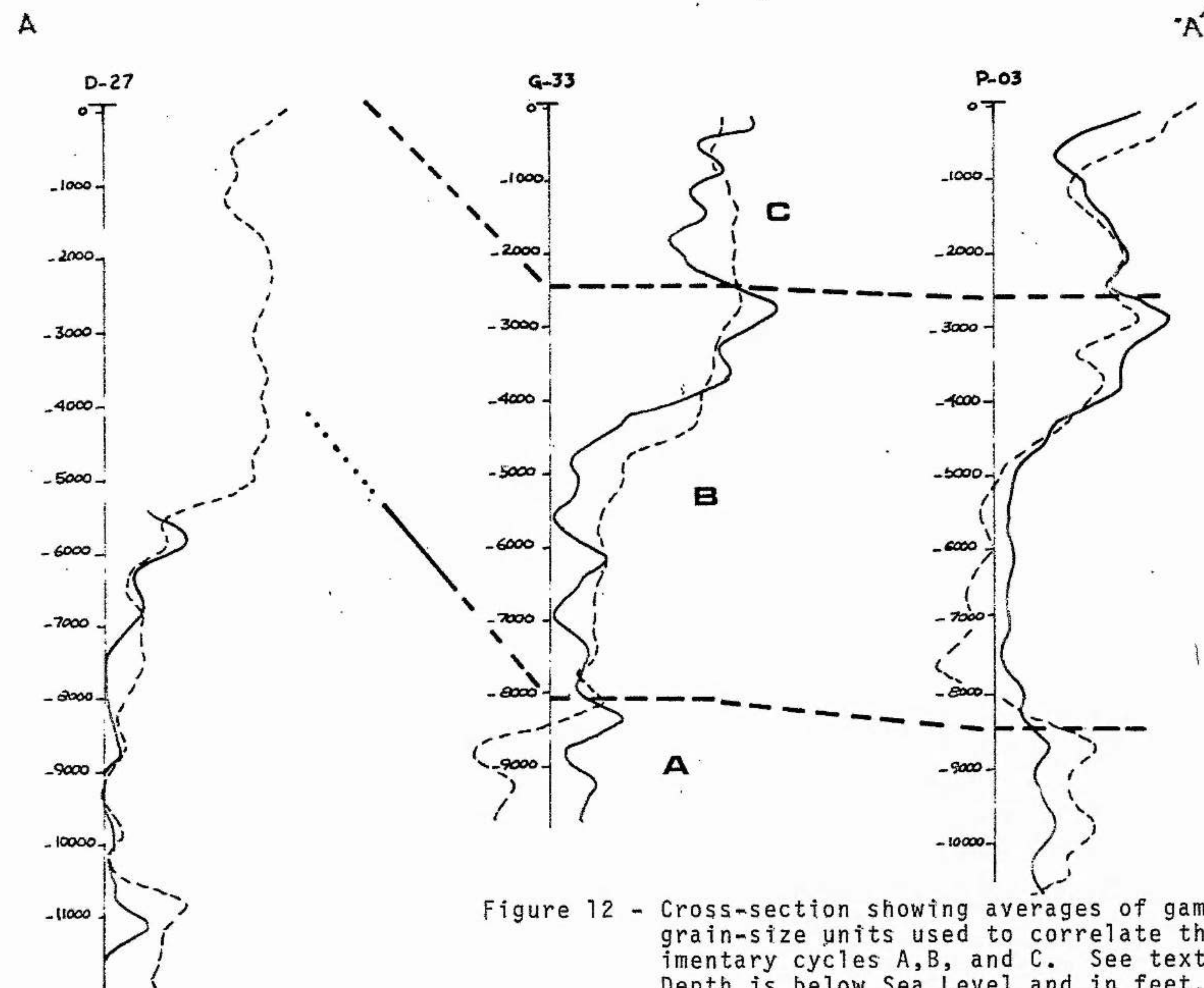
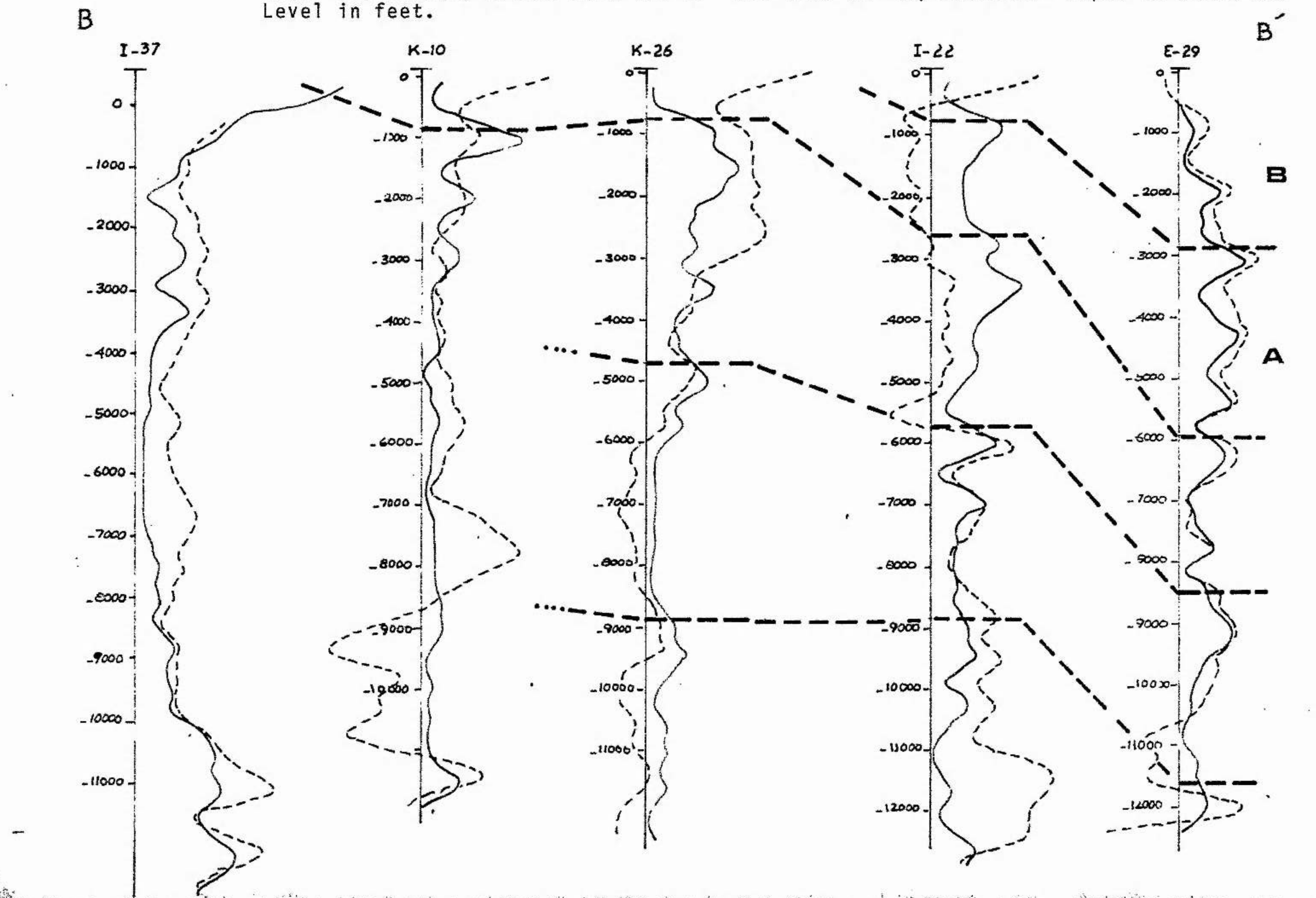


Figure 12 - Cross-section showing averages of gamma-ray and grain-size units used to correlate the major sedimentary cycles A,B, and C. See text for explanation. Depth is below Sea Level and in feet. Solid line is grain-siz

Figure 13 - Cross-section showing averages of gamma-ray and grain-size units used to correlate the major sedimentary cycles A,B, and C. See text for explanation. Depth is below Sea Level in feet.



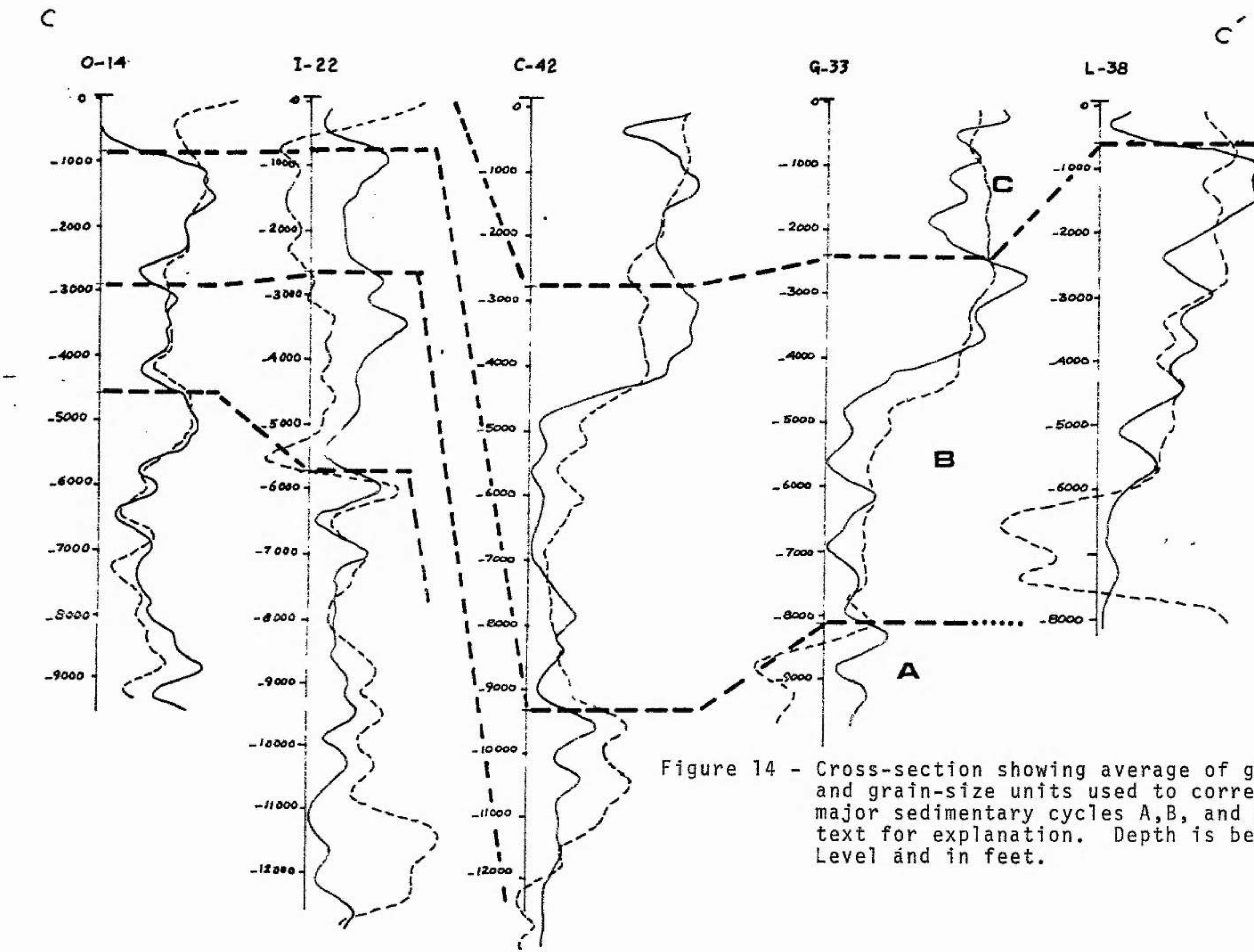


Figure 14 - Cross-section showing average of gamma-ray and grain-size units used to correlate the major sedimentary cycles A,B, and C. See text for explanation. Depth is below Sea Level and in feet.

become thinner and less obvious toward the Eskimo Lakes Arch Complex as can be seen in the Reindeer D-27 borehole. This change in thickness is expected in this direction since the edge of the basin was located in this general area during Tertiary time.

Correlation of Trace Elements

Trace elements are found in minute quantities adsorbed on the surface or integrated into the lattice of mineral grains. If found in the latter case they could be useful in the correlation of sediments to their source rocks and if they are absorbed on the mineral grains they could have environmental significance. Dennen (1967) used trace elements such as Al, Fe, Li and Ti in quartz to determine the provenance of the Perry Formation in southeastern Maine, U.S.A.

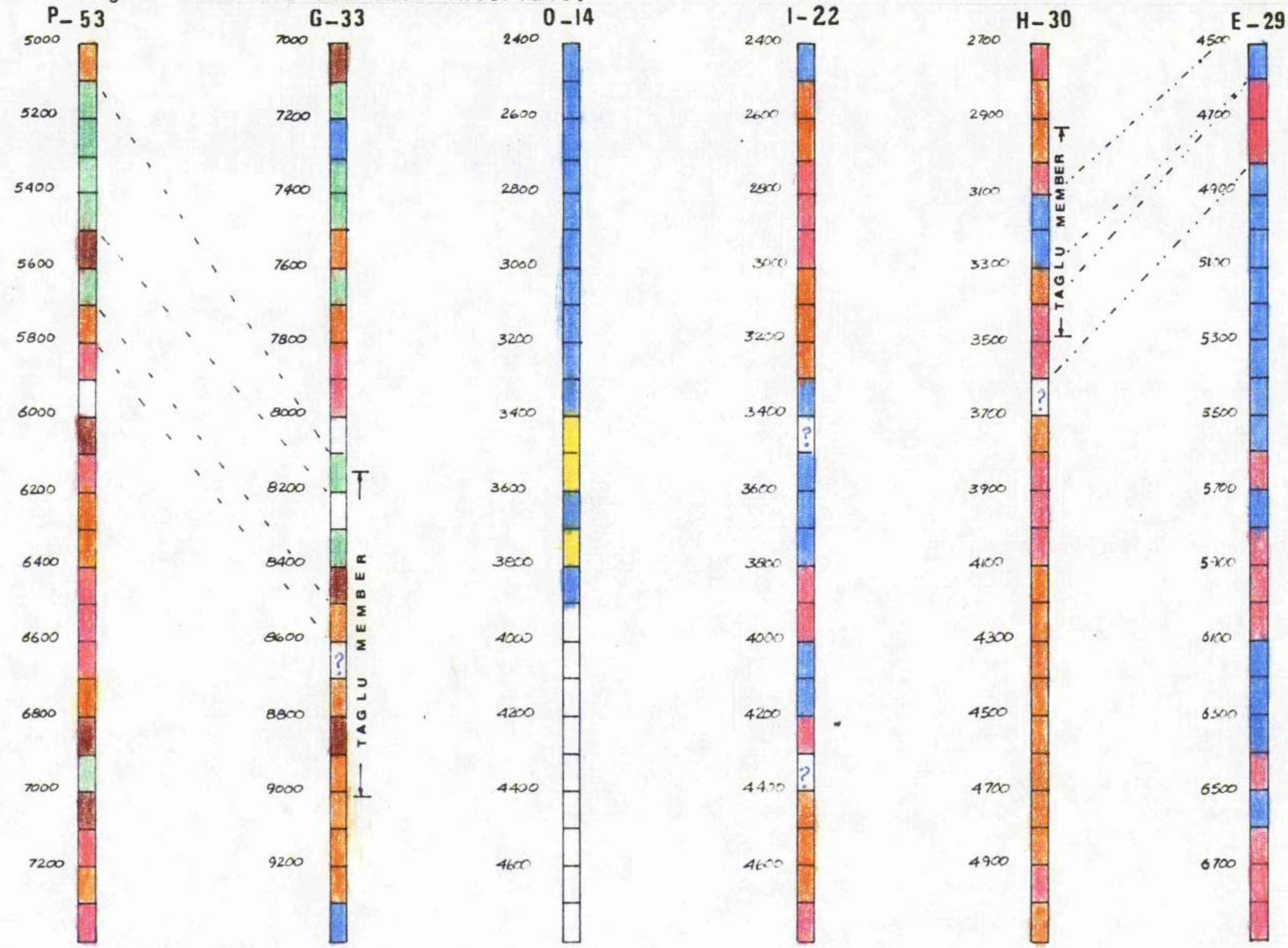
In this research shale samples totalling 152, were collected for trace element analysis (appendix A) from Niglintgak H-30, Langley E-29, Taglu G-33, YaYa P-53, Unipkat I-22, and Ellice O-14 boreholes. Each sample represents a composite section of 100 ft. (30 m). At the time when samples were collected the exact position of the Taglu Member was not known. Therefore, a 2000 ft. (610 m) interval from each of the five boreholes was sampled. Li, Ni, Cr, Mn, Zn, and Ti were analyzed by utilizing atomic absorption and Pb, Y and Zr were analyzed by X-ray fluorescence. The results were tabulated and plotted by computer as cluster analysis diagrams. The clusters were grouped based on the similarity level of the correlation coefficient (Fig. 15, in pocket). Each group was identified by a color symbol and all the samples within these groups were plotted in Fig. 16. This figure shows that a similarity in correlation co-efficients exists in Taglu G-33 and YaYa P-53 between the intervals 8100 ft. (2469 m) to 8600 ft. (2621 m) and 5100 ft. (1554 m) to 5800 ft. (1768 m) successively. Also a similarity exists in Langley E-29 and Niglintgak H-30 between the intervals 4500 ft. (1327 m) and 3100 ft. (945 m) to 3600 ft. (1097 m) successively. However, no similarity exists between E-29 and H-30 on one hand and G-33 and P-53 on the other (Fig. 16). This lack of correlation could be attributed to the fact that the sediments in the two groups of boreholes were deposited in different environments or derived from different source rocks as will be discussed in more detail in Chapter VI. Unfortunately, no apparent similarity of correlation co-efficient exists between the rest of the boreholes.

Biological Correlation

Biological correlation is based wholly on spores and pollens. Microfauna did not produce satisfactory results. Changes in the environment of deposition from marine to transitional to continental put limits on the distribution of microfauna.

Palynology proved less dependent on environment and was helpful as an aid to correlation and as an age determinator. In the Mackenzie Basin palynology is used for regional and local correlation. In this research it was used for gross correlation alone because only long ranging forms grouped in assemblages or zones are available in literature. As discussed in Chapter III the Taglu Member falls near the top of the *Pesavis tagluensis*

Figure 16 - Similarity plots of trace elements analyzed by X-ray and Atomic Absorption. Each box identified by a color symbol representing a 100 ft. composit sample. Depth of samples is recorded in feet. In 0-14 and I-22 the Taglu Member is higher than the examined intervals.



zone named by Austin and Cumming (1976, 1977).

Correlation of Gamma-ray Logs

Gamma-ray log serves as an excellent tool for local and regional correlation of rock units. It can be used to identify several different lithologies such as bituminous shale, shale, clean sandstone, shaly sandstone, calcareous sandstone, siltstone and coal. With experience recognition of the response of the log to different lithologies becomes straightforward unless mica and feldspar are present in abundance to affect the log. Radioactive isotopes of various elements,especially potassium 40, affect the response of the gamma-ray log.

Gamma-ray log measures the radioactivity of the rock-forming minerals. This measurement is recorded in API units. Bituminous shale and coal show the highest reading and clean sandstone the lowest. Radioactive minerals seem to be associated closely, in general, with grain size: the smaller the grain size the higher the API reading, and the coarser the sediment the lower the reading. This remarkable association with grain sizes was demonstrated in Figure 12.

The Taglu Member with its lithofacies shows a distinct gamma-ray response. Therefore, it was relatively easy to correlate it from one borehole to another within the Mackenzie Basin. Closer to the edge of the basin, facies changes occur and here other correlation techniques had to be used.

Application of Correlation Methods

Correlation of the Taglu Member and the overlying "Unnamed Shale" in the research area was first accomplished regionally by using seismic profiles. Unfortunately only three seismic cross-sections were permitted by the operating companies to be published in this report. However, more seismic cross-sections and profiles were available and in fact they contributed a large volume of data on correlation and structural framework of the Mackenzie Basin. This correlation provided a general knowledge about the lateral extent and the approximate depth of the Taglu Member over a wide area within the basin. This knowledge was further improved by correlating the major sedimentary cycles of the Tertiary. Correlation of the sedimentary cycles would have not been accomplished without the help of seismic data. The sedimentary cycles provided better information regarding the depth of the Taglu Member, especially where seismic reflections are poor, and to its gross facies change.

Trace elements correlation was attempted in that part of the second sedimentary cycle of the Taglu G-33 within which the Taglu Member is present. This correlation did not contribute substantially to solving the problems since only six boreholes were used and the trace elements used proved unreliable for fine correlation. They showed, however, that there is better correlation between YaYa P-53 and Taglu G-33 on one hand and between Langley E-29 and Niglintgak H-30 on the other as far as the Taglu Member is concerned (Fig. 16).

After using the above mentioned gross correlation methods an attempt was made to correlate the lithofacies of the Taglu Member and its equivalents. Therefore, a detailed interpretation of the depositional environment of the type section of the Taglu in Taglu G-33 was made and it was concluded that this member represents the record of two deltaic cycles. Lithofacies 1 and

2 (Fig. 7) represent the lower cycle and lithofacies 3 and 4 represent the upper cycle. Furthermore, Shawa et. al.,(1974) studied the environment of depositon of the rock unit which constitutes a large part of the Taglu Member, as a complete deltaic sequence. This sequence includes a prodelta, delta front, distributary mouth bar, and the fluvial channels of the Upper delta plain. This sedimentary cycle indicates that the rock sequence which contains the Taglu Member shows lateral coarsening of grain size in a southerly direction and a fining in a northerly direction suggests a general source area to the south. This was further supported by the general configuration of the Mackenzie Basin as indicated by seismic profiles. Based on this background, a sedimentological model for the Taglu Member was constructed. This model is based on present-day knowledge obtained on the lateral and vertical distribution of lithofacies within delta complexes as reported by Fisher et. al., 1969; Coleman and Gagliano, 1964; Allen, 1970; and Brown and Fisher, 1976. Delta lithofacies become thinner and coarser grained toward the delta apex. Also, the sandstone to shale ratio becomes higher in this direction. Applying this model on the Taglu Member one would expect to encounter a thinner interval and a higher sandstone to shale ratio toward the south, southeast or southwest. In this direction one would also expect a coarsening in grain size demonstrated by the sedimentary cycle discussed above, accompanied by a change in environment to one more dominated by fluvial processes. Having this model in mind and using the above discussed gross-correlation methods, correlation of the Taglu lithofacies was accomplished (Figs. 17, 18, 19). This was supported by palynology and the presence

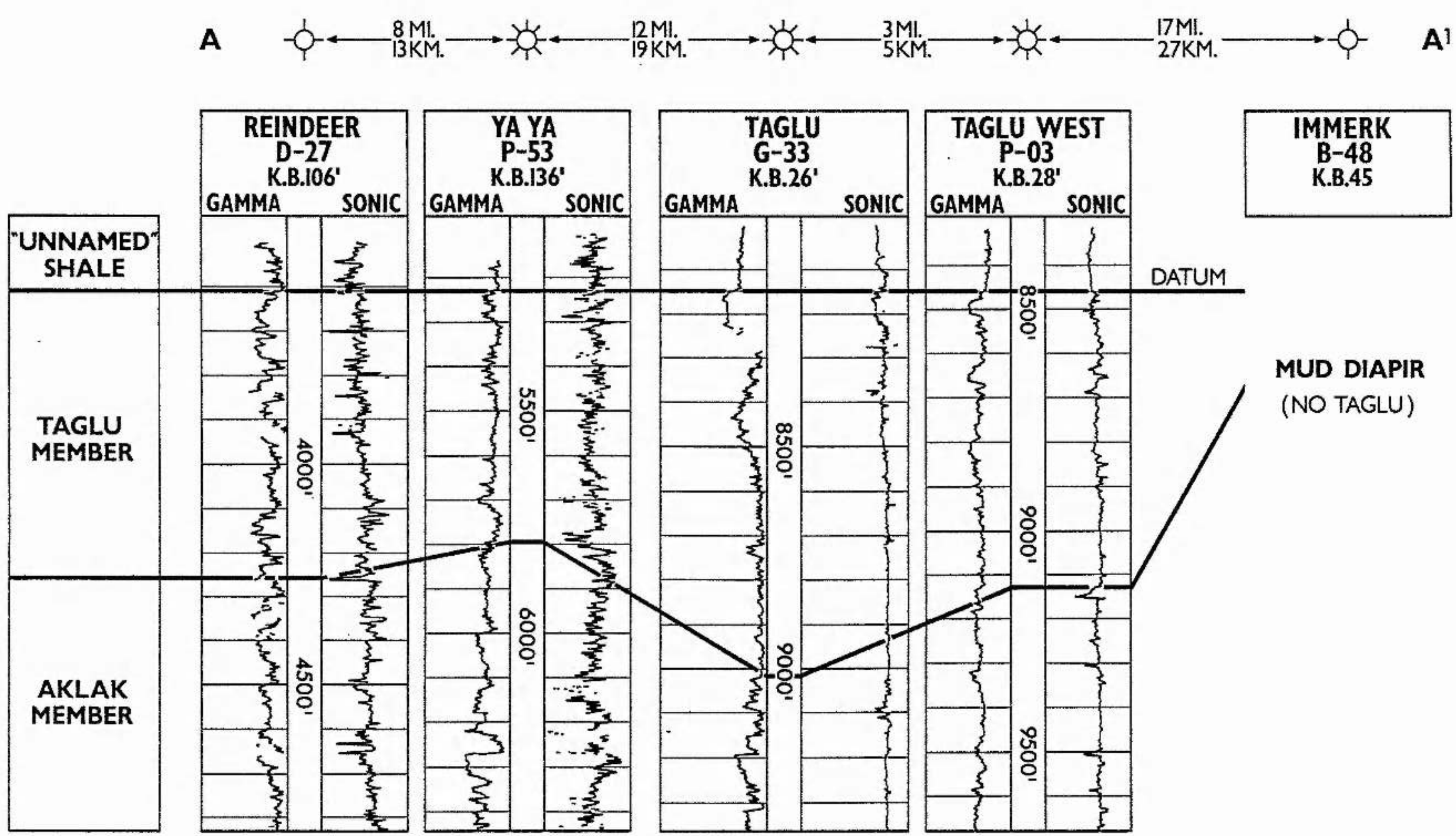


Figure 17 - Stratigraphic cross-section A-A' illustrating the correlation of the Taglu Member. This correlation is also supported by lithology.

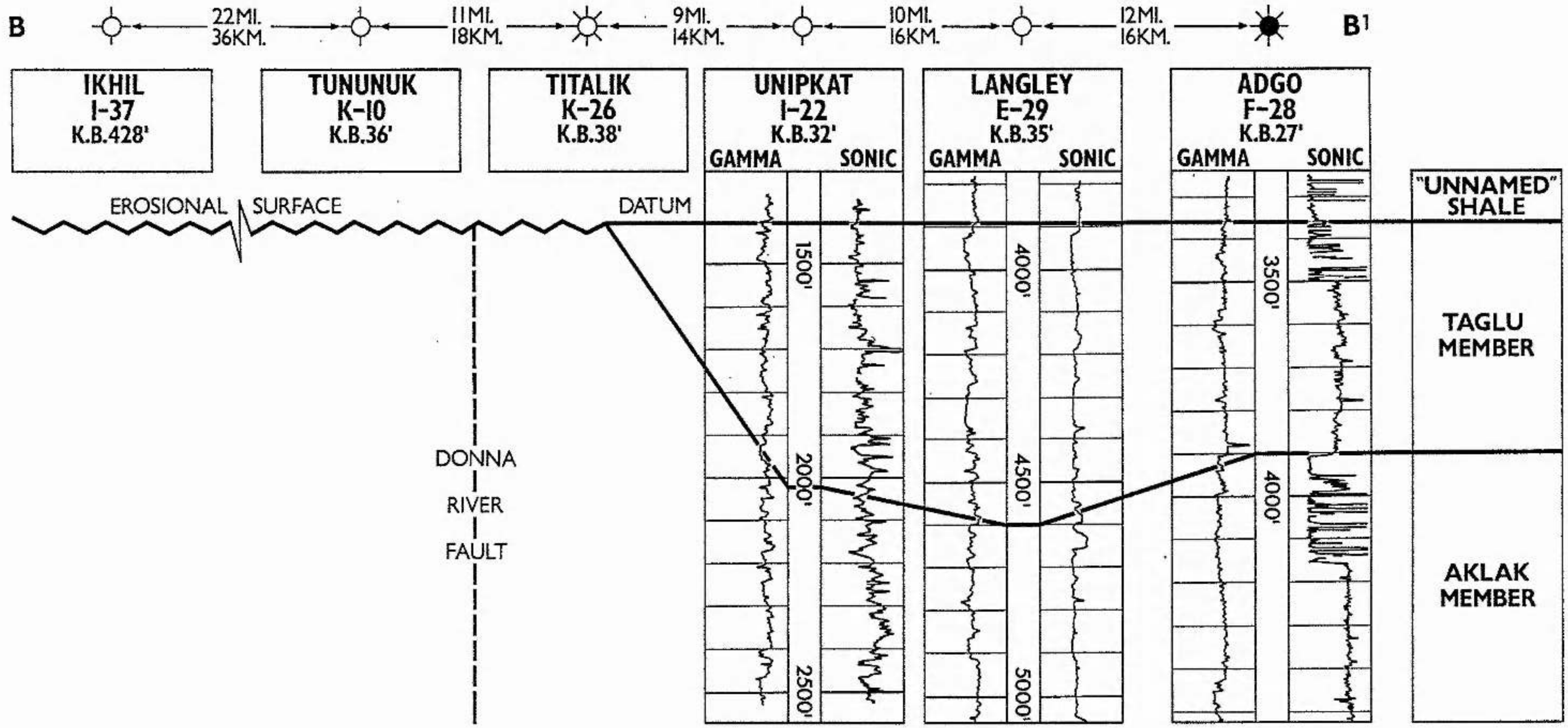


Figure 18 - Stratigraphic cross-section B-B' illustrating the correlation of the Taglu Member. This correlation is also supported by lithology.

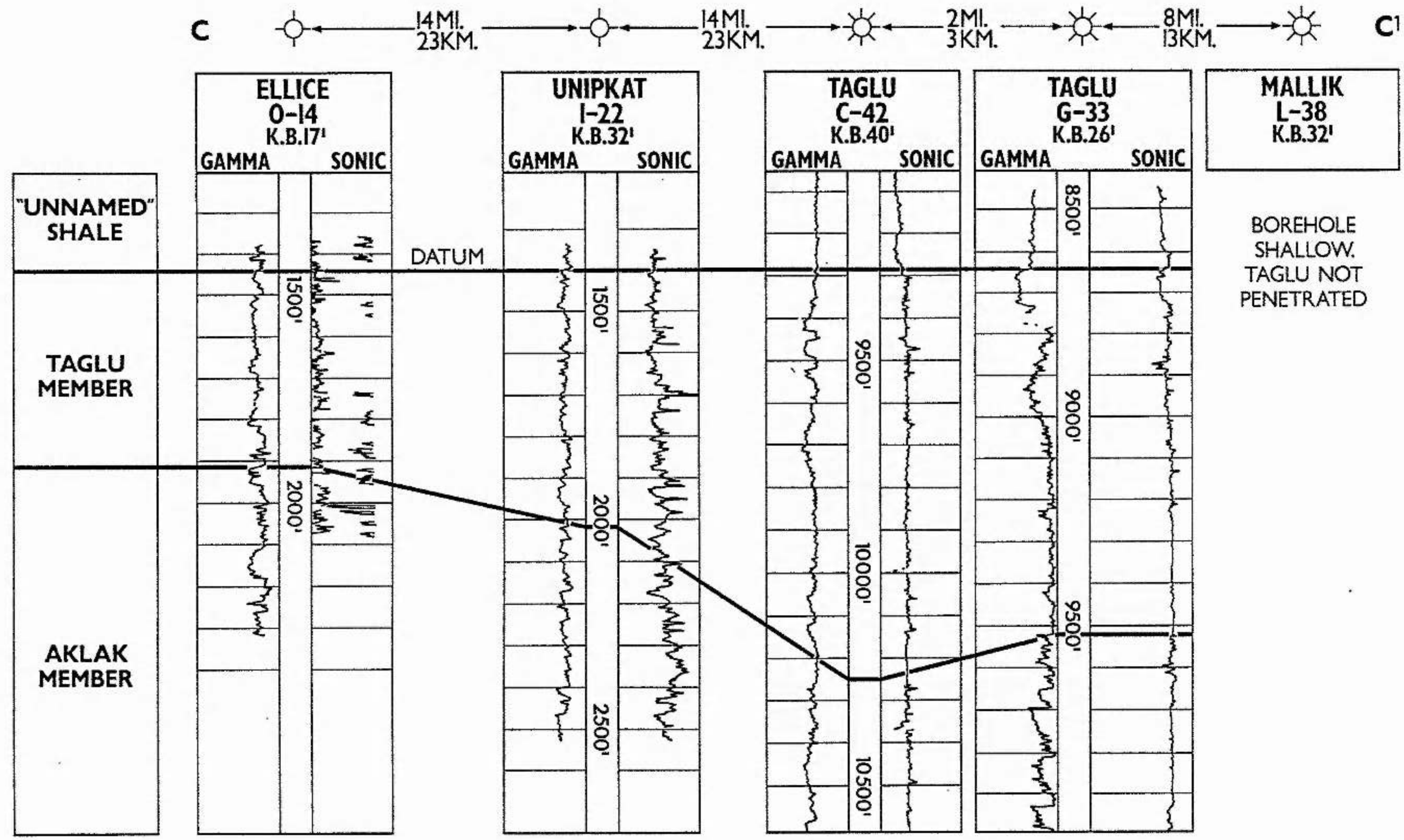
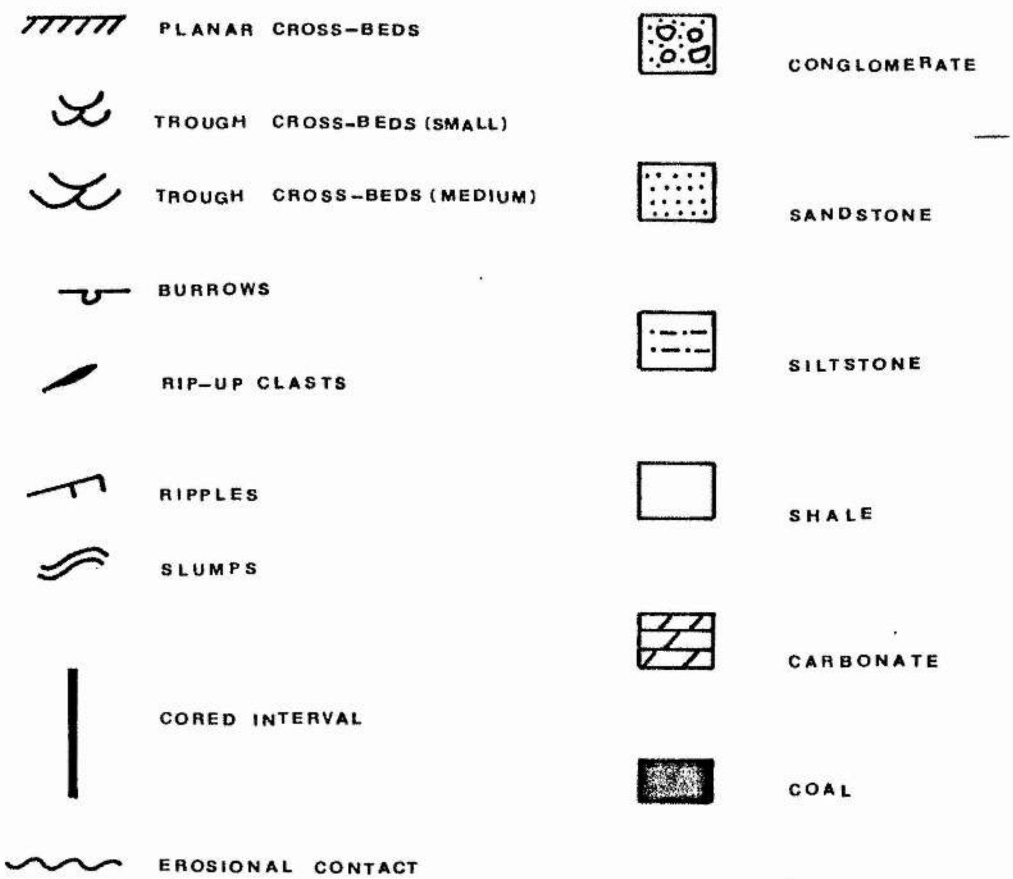


Figure 19 - Stratigraphic cross-section C-C' illustrating the correlation of the Taglu Member. This correlation is also supported by lithology.

of a distinct zone in the upper part of the Aklak Member just below the lower contact of the Taglu Member. This zone consists of sandstone intervals ranging in thickness between 40-100 ft. (12-30 m) that are repeatedly interbedded with shale. The sandstone intervals show an upward increase in grain size from very fine to fine or medium. Their upper contact with the overlying shale is usually abrupt. These sandstone intervals show very clearly on most gamma-ray logs. Toward the south this characteristic zone of the upper Aklak becomes less distinct.

FIGURE 20
SYMBOL EXPLANATION



CHAPTER V

SEDIMENTOLOGY OF THE TAGLU MEMBER

Sandstone composition and texture of the Taglu Member varies from place to place. Its general composition, however, is very similar to that of the Aklak Member which was studied by Young (1975). The similarity in composition between the two members makes it difficult to differentiate one from the other. One hundred thin sections were examined for this research. Out of these thin sections 72 were point counted using an average of 250 points per thin section. The results were tabulated on special forms which are not enclosed in this report. These results, however, are summarized in Appendix B.

The amount of published petrologic work on the Taglu Member is negligible. The following is a description and analysis of the primary rock particles and their cementing material. Primary rock particles were identified in thin section and the cementing materials were identified both in thin sections and by Electron Scanning Microscopy.

Based on its composition the Taglu sandstone can be classified as quartz arenite and sublitharenite (Fig. 21). Only a minor part of the sandstone can be classified as feldspathic arenite.

Petrology

<u>Primary Rock Particles</u>: The Taglu Member consists predominantly of quartz, chert, feldspar, rock fragments, micas, and opaque accessory minerals.

<u>Quartz</u>: One of the most abundant primary rock particles of

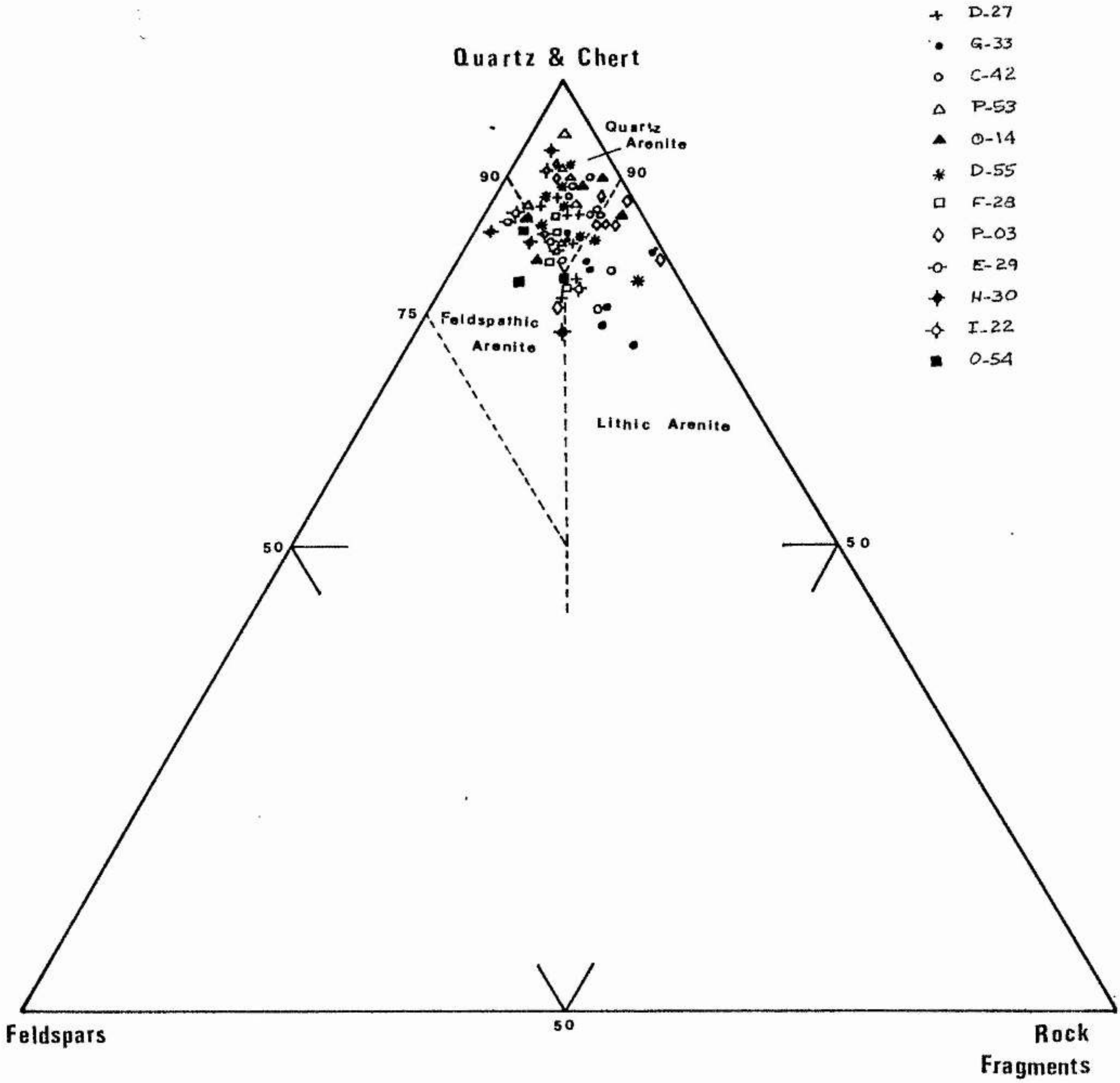


Figure 21 - Classification diagram showing the ratio of silica to rock fragments to feldspar in the Taglu Member.

the Taglu Member is quartz. It comprises 19 to 56% of the rock (Fig. 22) and is present as monocrystalline and polycrystalline types. The former type is by far the most abundant and it displays straight to slightly or strongly undulose extinction. The latter type is finely or coarsely crystalline (greater than 5 crystals units per grain). Polycrystallinity in quartz was observed in the larger than fine size grains. Quartzite is present in minor amounts as granules and pebbles of which no thin sections were prepared, in the very fine size and silt grains only monocrystalline quartz was observed. The absence of undulosity in these fractions could be attributed to the fact of breaking down of polycrystalline grains to individual crystals. A relationship also exists between undulose extinction and grain size. Anderson and Picard (1971) found that non-undulatory extinction generally increased with a decrease in grain size especially in the silt fraction.

Inclusions in quartz are present in small quantities. They consist of vacuoles and microlites. These inclusions can be found in all types of quartz and in all size of grains. The most abundant microlites consist of apatite followed by zircon. Illite crystals are also present occasionally in quartz grains.

Corrosion and replacement are common phenomena in the quartz of the Taglu Member. The larger grains show less corrosion. Some of the corrosion is probably the result of optical illusion (Folk, 1964) where small areas of the carbonate cement overlap the edge of the quartz grain.

The average grain size of the quartz differs from place to place. It ranges from 3.5 Ø to 1.0 Ø. Most grains are subrounded and subangular although a few angular grains were observed. The

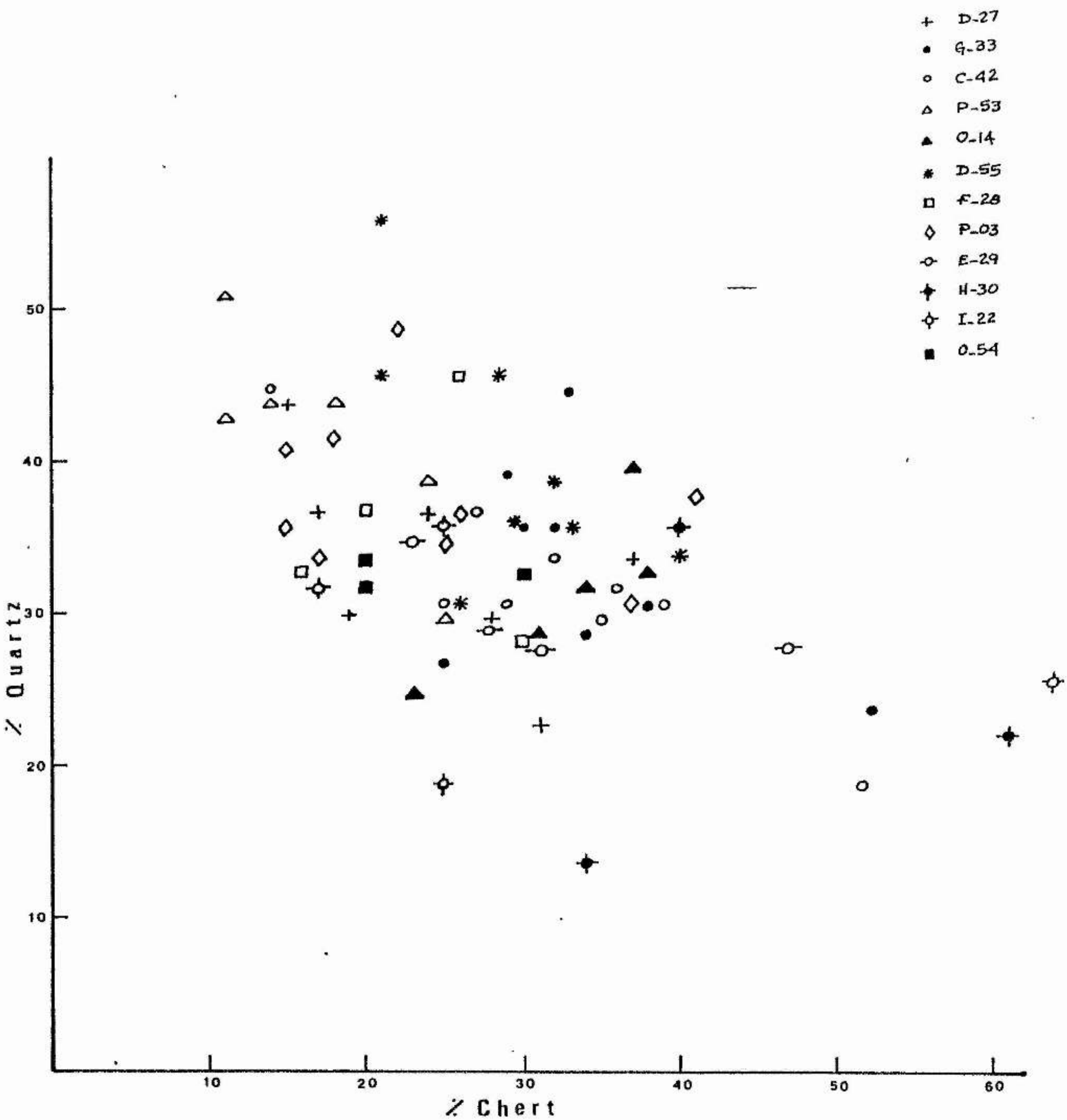


Figure 22 - Diagram showing percent distribution of quartz and chert in the Taglu Member.

grains are equidimensional or slightly elongated and strongly elongated quartz was observed occasionally. Some quartz grains exhibit silica overgrowth and dust rims (Plate II). In some cases the overgrowth was formed after deposition due to an increase in the overburden pressure as indicated by the pressure solution phenomenon (Plate III) where the contact between grains is concavo-convex.

Chert: Like quartz chert is one of the most dominant minerals in the sandstones of the Taglu Member. It comprises 11% to 62% of the rock (Fig. 22) and is present in three types. One type consists of aggregates of equidimensional crystals that could be very finely, finely or coarsely crystalline (Plate IV). The second type occurs as a fracture in-fill in quartz, and the third type occurs as cement. The first type is the most widely distributed and the third type is very rare. Chert grains of the first type are the product of reworking from an older sedimentary source. Hence, they are useful in determining the source areas of the Taglu sandstones.

The aggregate crystals of chert are predominantly equant. In a few cases, however, the crystals are elongated. Not all chert is pure silica; a large volume of it consists of a very impure aggregate. Silt, organic matter and mica are the most abundant impurities (Plate V). The impure chert is brown and in some cases almost black and opaque. A few impure chert grains exhibited narrow bands of pure chert running across the grain (Plate V). Small sericite crystals, some of which exhibit a parallel orientation, were seen occasionally in the pure chert (Plate VI). When secricite is present in abundance the grain was identified as a metamorphic rock fragment.

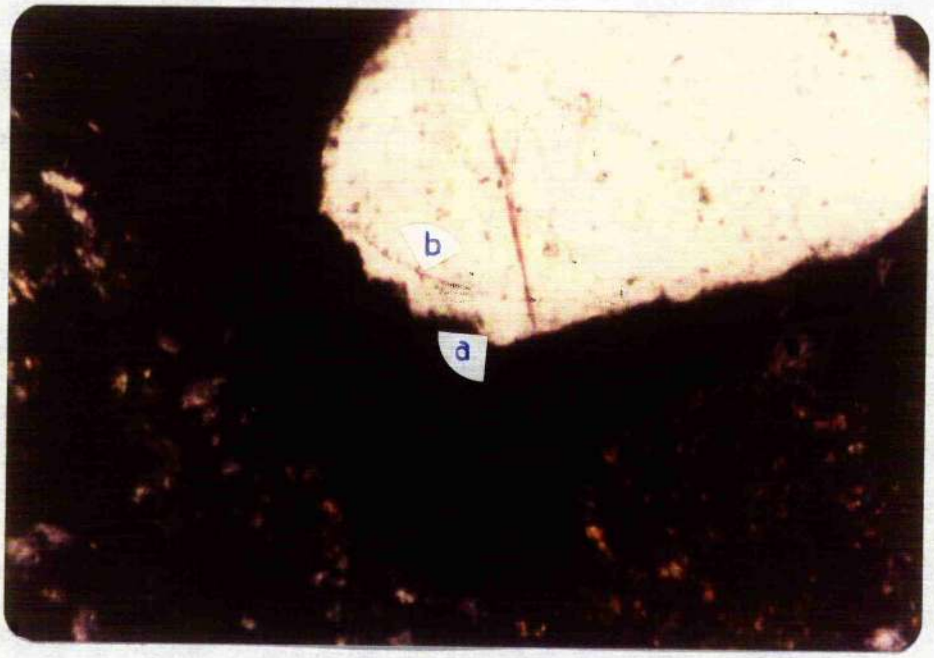


Plate II - Silica overgrowth (a) on a quartz grain. Notice dust rim (b) between grain and the overgrowth as seen in thin sections. 375X, H-30 at 3600-3640 ft.

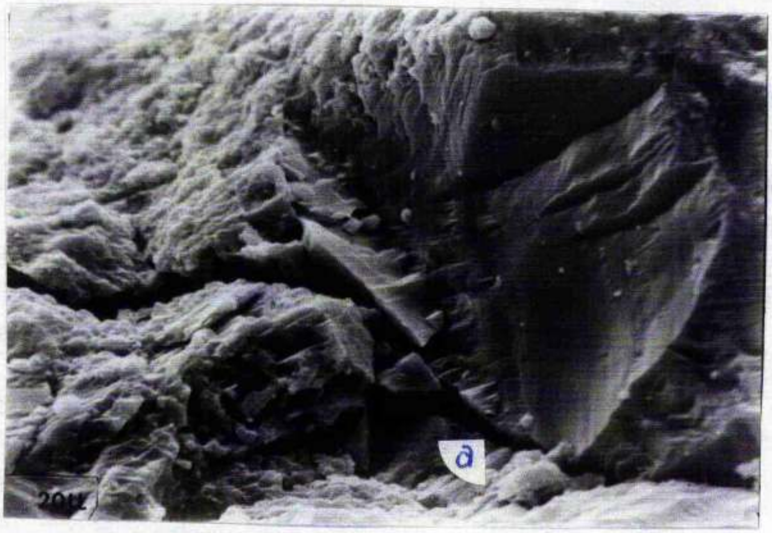


Plate III - SEM photomicrograph showing pressure solution phenomenon (a) between two grains 2000X, H-30 at 3200-3220 ft.

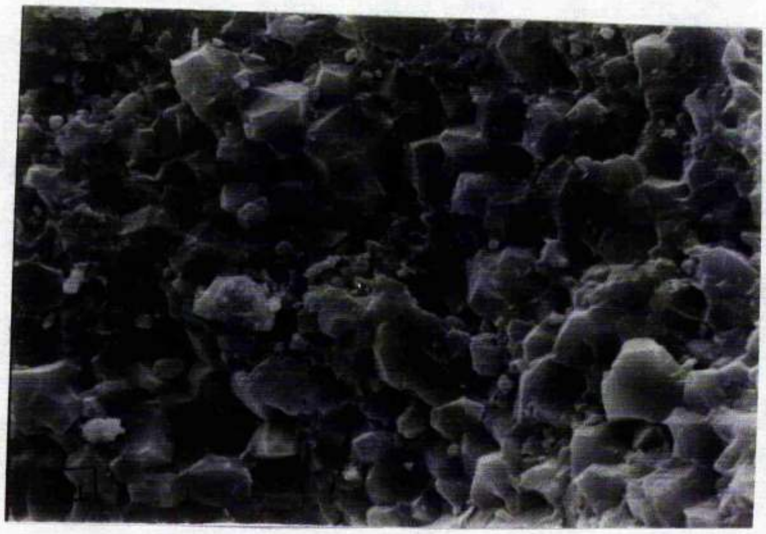


Plate IV - SEM photomicrograph showing the surface of a chert grain which consists of many individual crystals. 5000X, 0-14.

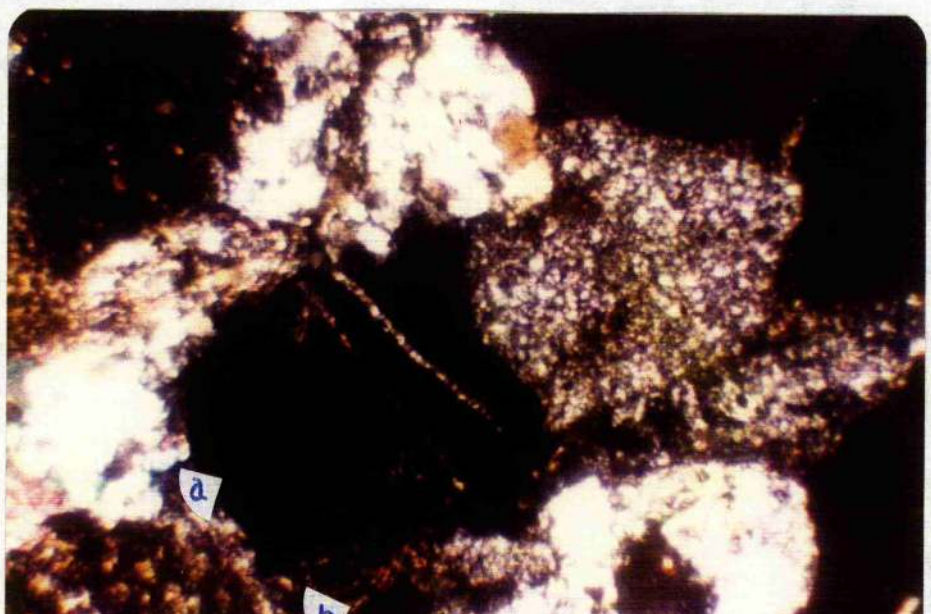


Plate V - Thin section photograph showing impure chert grain (a) with narrow bands of pure chert running across the grain. Small flakes of mica (b) are present occasionally in some chert grains. 375X, 0-14 at 1802 ft.

The average grain size of chert ranges from 2.0 Ø to 1.25 Ø. They are subrounded and rounded especially the smaller sizes. Chert seems to be softer than quartz and feldspar. These two minerals indent chert where high compaction is observed. Most of these chert grains are equidimensional or slightly elongated. The slightly elongated grains show signs of stretching where the individual aggregate crystals are stretched.

Feldspar: Both plagioclase and orthoclase are present in most thin sections in quantities always less than 8%. The amount of authigenic feldspar in the thin sections was almost nil and in many cases totally absent. Plagioclase, as a rule, is more abundant than orthoclase and seldom shows signs of weathering. Unlike quartz, feldspar is not replaced by the carbonate cement. The distribution of feldspar in the Taglu Member sandstone is almost uniform in concentration. Microcline, in spite of it being more resistant than the rest of the feldspar, is present only in a few samples.

Plagioclase was identified with certainty in thin sections if it showed twinning. Untwinned plagioclase is easily mistaken for quartz or orthoclase and some grains were probably counted as such. Fresh plagioclase does not exhibit inclusions and the slightly weathered grains show specks of scattered dust.

The average grain size of feldspar ranges from 3.0 Ø to 1.5 Ø. Generally, they are subrounded and equidimensional. Orthoclase is better rounded than plagioclase. Grains of the latter are more angular in some thin sections.

Rock Fragments: Most thin sections contain less than 15% rock fragments which consist mainly of sedimentary and metamorphic clasts. Volcanic rock fragments are rare or absent. Metamorphic rock fragments are, generally, more common in the coarser size fractions of the Taglu Member. They are, however, found in every examined borehole. Sedimentary rock fragments on the other hand are more common in the finer size fractions.

The average size range of rock fragment is between 2.0 Ø and 1.0 Ø. They are usually slightly larger than the surrounding grains and in all cases better rounded regardless of their size.

Mica: Both muscovite and biotite are present and constitute less than 10% of sample components. Muscovite does not show any signs of alteration and is present in small and large crystals. Plate VII shows a small crystal of muscovite between quartz overgrowth and the surface of a quartz grain. Muscovite as well as the biotite, especially the large crystals, show effect of compaction in those places where crystals are deformed around the grains. This phenomenon was observed in the northern and western part of the research area where the Taglu sandstone exhibits a high degree of compaction. Muscovite is associated mainly with the finer size fractions. It is by far the dominant mica mineral. Biotite shows signs of alteration and in a few places it is altered to chlorite or kaolinite.

Along the edge of the basin and toward the eastern and southern limits of the research area muscovite is represented by very small sericite crystals that can be mistaken for illite, but toward the north and northwest, that is toward the deeper part of the basin, sericite becomes coarser. This phenomenon is related to depth of burial. These small crystals of muscovite are generally present in a preferred orientation around the other grains. They are seldom perpendicular to other grains.

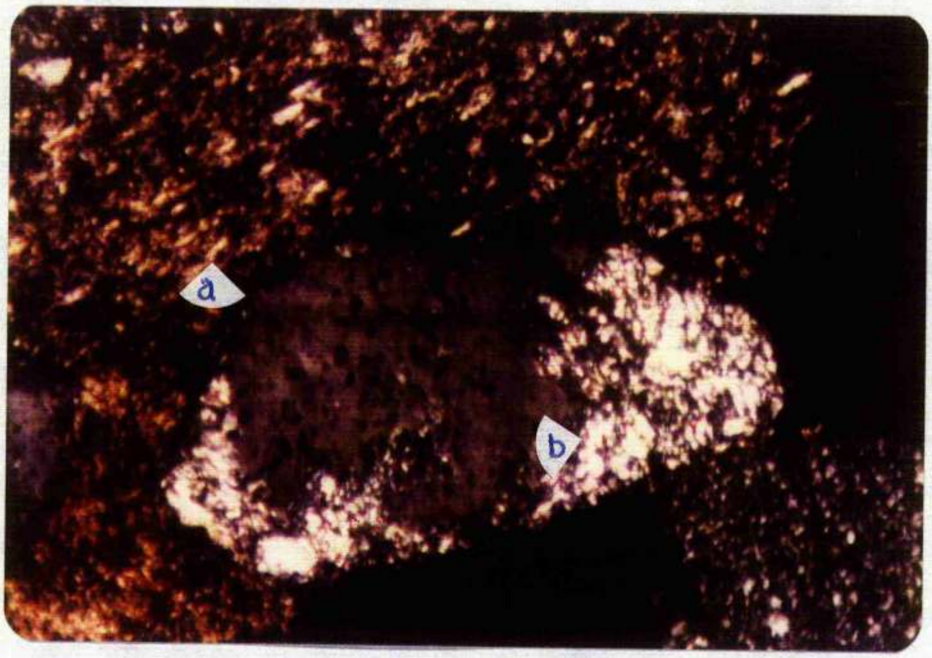


Plate VI - Thin section photograph showing sericite crystals (a) in a chert grain in the upper part and a quartz grain replaced by dolomite (b) 375X, 0-14 at 1470-1480 ft.

Plate VII - SEM photomicrograph showing a small crystal of muscovite (a) among quartz overgrowth. 1000X, G-33 at 8374 ft. Mineral in centre is chlorite.

Opaque and Accessory Minerals: These are found in all sand size fractions of the Taglu Member. The opaque grains consist of pyrite and organic fragments including coal chips. Ferric oxide - hematite staining is found coating sand grains. The organic fragments are black or very dark brown. They are concentrated in thin laminations or scattered throughout. Opaque grains constitute less than 8% of the thin sections.

The accessory minerals consist, chiefly, of detrital dolomite grains, detrital particles and to a lesser degree unidentified minerals which seem to be the product of alteration. The detrital dolomite is rich in iron as can be concluded from staining by potassium ferricyanide. They constitite less than 1% of the thin sections. The dolomite is of diagenetic origin, having replaced limestone.

Cement: The crystallizing material which precipitates chemically from solutions in the rock pores is referred to as cement. It is dependent on the mineralogy and grain size of the host deposit as well as on the composition of the solutions in the pores. Cement could form early within the sediment/water interface at normal conditions of pressure and temperature or late after burial of the sediments. Early cement is usually closer to the grains, while the later type fills the rest of the pore space. Both types of cement are present in the Taglu Member and consist of dolomite, calcite, siderite, silica, and clays. The cement constitutes no more than 25% of the thin section and in many cases much less. Identification of the cement was accomplished by a petrographic microscope and by scanning electron microscopy. Two scanning electron microscopes were used during the course of study; one is an ICI model II, and the other a Cambridge 600 with an X-ray energy dispersive unit giving element spectrums.

Cementation is the most important process in reducing the porosity in sandstone by occupying the pores and in reducing permeability of the rock by restricting pore throats.

Dolomite: the most abundant cement by far is dolomite. It is anhedral and euhedral in form consisting of large and very small crystals. In larger pores the euhedral dolomite is present showing one single orientation, and in the smaller pores the anhedral type is more common. Some pores, however, exhibit both types. ~~Since dolomite does not crystallize from sea water or similar solutions at surface temperature and pressure, one would conclude that it was formed late in the diagenetic history of the sandstone.~~ The dolomite is both ferroan and non-ferroan. The ferroan consists always of small crystals. The identification of both types is based on the staining of thin sections with potassium ferricyanide solution. The iron-deficient dolomite does not stain, while the iron-rich variety stains deep, dark blue.

The crystal size and the abundance of dolomite cement varies from place to place. Crystal sizes range from microcrystalline to macrocrystalline and the amount of cement is inversely proportional to that of the clay-size matrix. The distribution of dolomite is erratic, however, it increases towards the eastern limit of the research area. Dolomite cement is controlled to a large degree by the environment of deposition and it will be discussed in more detail in chapter VII. It constitutes up to 26% of any thin section.

Dolomite cement occurs in three different states. One, it may be forming a thin zone around grains, two, in places it replaces part of the grain especially that of quartz, and three, it may be pervasive. ~~making the rock cement supported.~~ The third state of dolomite consists of ferroan, this is the more common, and non-ferroan (Plate VIII). In almost all thin sections dolomite cement was observed replacing quartz grains. In several places the replacement is well advanced as shown in Plate (VI) where a large part of the quartz grain was replaced by dolomite.

Calcite: The only type of calcite observed in thin sections is non-ferroan. This identification is based on staining techniques. The thin sections were stained with Alizarin Red S which stains the non-ferroan and ferroan calcite different shades of red and purple depending on the concentration of iron in the calcite. Calcite cement constitutes up to 15% of the thin section. It consists of large and very small crystals. The moderate occurrence of calcite indicates that it has been replaced by dolomite during burial. Calcite cement mainly occurs in patches of macrocrystalline sizes exhibiting one single optical orientation (Plate IX).

Siderite: Siderite cement was found in the medium, coarse and very coarse size fractions which are rich in coal chips. It consists of brown, microcrystalline or amorphous material coating the sand particles (Plate X). It could be mistaken for dolomite.

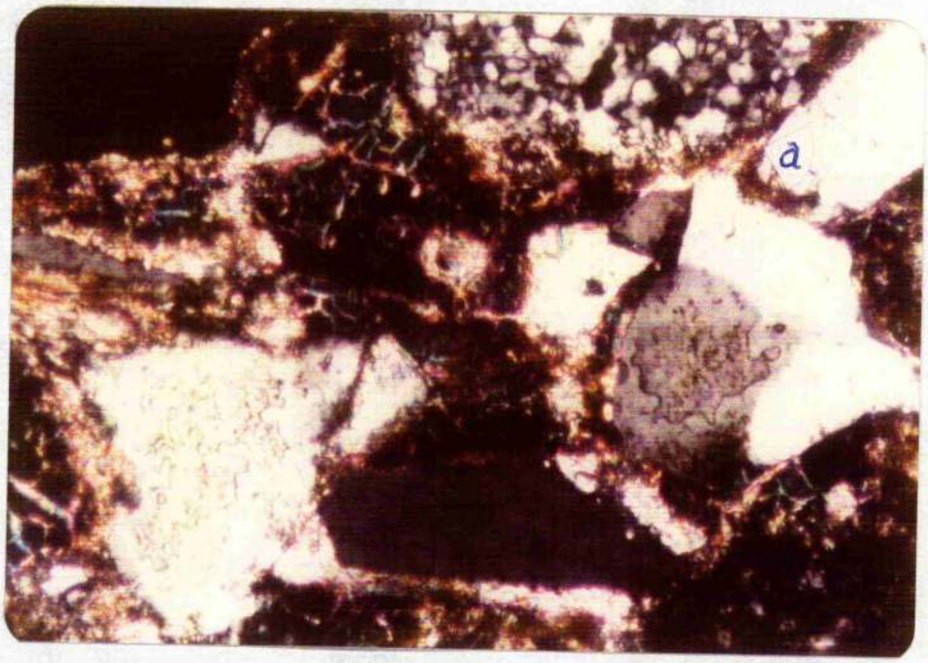


Plate VIII - Thin section photograph showing non-ferroan dolomite cement (a) around many quartz and some chert crystals and ferroan dolomite (Blue) near the centre of the pore. 375X, 0-14 at 1460-1480 ft.

Plate IX - One large crystal of non-ferroan calcite (red) in a pore as seen in a thin section. 375X, 0-14 at 1470-1480 ft.

Occasionally siderite cement is segregated, forming small patches in pore spaces. It constitutes less than 8% of the thin section and it is distributed throughout the research area. In places siderite forms nodules or is segregated in thin beds 2-3 cm thick. The nodules vary from sand to pebble size as was observed in core samples (Plate XI). Some siderite cement was altered to iron oxide changing its original color to very dark brown which coats the grains.

Silica: Some quartz grains exhibit secondary overgrowth of silica with the same optical orientation of the original grain. The secondary overgrowth is present in two stages; one consists of small secondary rhombohedral crystals growing on a larger grain of quartz (Plate VII) and the other is a more advanced silica overgrowth which is enlarging the original quartz and forming straight boundaries (Plate II). Quartz overgrowth starts as numerous incipient crystals on quartz grains. These ultimately merge into one larger crystal of overgrowth. Silica overgrowth constitutes up to 7% of the thin section and is mainly found where the Taglu is at a greater depth and near the depositional edge of the sandstone in the northern and western part of the research area.

The origin of silica could be the result of pressure solution (Waldschmidt, 1941) which dissolves quartz at contact points of grains. Silica also may have formed from solution of the finer quartz particles in the matrix between grains as pointed out by Goldstein (1948). Decomposition or alteration of silicate is another source for the silica overgrowth (Pye, 1944).

The pressure-solution phenomenon is not advanced in the

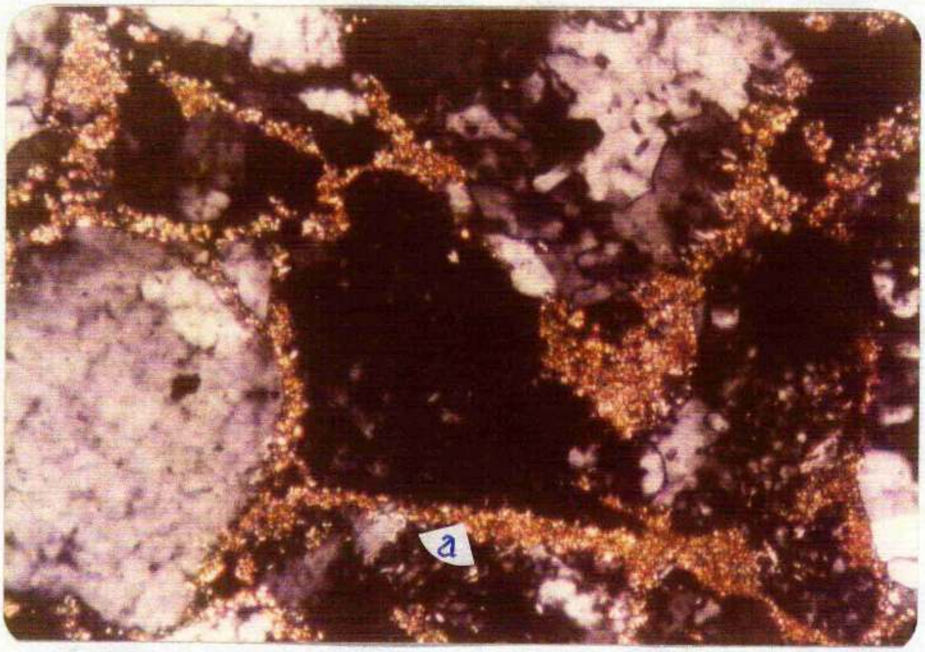


Plate X - Thin section photograph showing amorphous siderite coating (a) the sand particles. 375X, D-27 at 3900-4000 ft.

Plate XI - Photograph of a conventional core sample showing a siderite nodule near centre. size 1:1, D-55 at 10442 ft.

Taglu sandstone; few cases of convex-concave grain contacts were observed. This phenomenon, which is produced by high overburden pressure could have been responsible for the silica overgrowth in the Taglu Member of the Taglu Field because the member is here at a great depth. The presence of natural gas in sandstone horizon prevents precipitation of chemical cement such as silica in rock pores (Füchtbauer, 1961; Philipp et. al., 1963). This could explain the low percentage of silica overgrowth in the Taglu gas producing boreholes G-33, P-03, and C-42 and its relative abundance in the dry Taglu D-55 borehole.

Silica overgrowth consisting of small quartz crystals must have had a different origin than pressure solution. It does not seem to correlate with overburden pressure since it is found in almost every borehole regardless of depth or the presence of natural gas. It will be discussed in more detail in Chapter VII.

Clays: Authigenic clay minerals represented in the Taglu Member are kaolinite, chlorite and illite. They do not constitute more than 14% of thin sections and are present in every borehole and every lithofacies. Authigenic clays form as a result of precipitation from solution presumably at or near the depositional interface; hence, they are a valuable tool in determining the environment of deposition. They precipitate on grains but not on dolomite or calcite cement except in rare cases where illite was seen on calcite.

Besides authigenic clays, diagenetic clays and detrital clay particles are also present although in minor quantities. Diagenetic clays are the product of replacement where a detrital grain such as muscovite can partially or completely be replaced by kaolinite. Also this type of clay can replace authigenic clay as is the case of illite replacing kaolinite (Millot, 1970). Detrital clay particles, on the other hand, are inherited from the source area and were deposited with the rest of the sand particles. They are difficult to identify in thin section and have no environmental significance, hence, they were disregarded and considered as accessory minerals.

Identification of authigenic clays was based on composition and morphology. Authigenic clays are of pure composition (Keller, 1970) and have uniform color and texture (Lerbekmo, 1961). They are monomineralic unlike the other clays which are generally a mixture of two or more clays. Morphology is a very reliable criterion for the identification of authigenic clays (Wilson and Pittman, 1977). This type of clay exhibits crystalline habits with obvious crystal outlines (Smithson and Brown, 1954).

Authigenic clays in the samples examined occur as pore lining or pore filling. Chlorite and illite occur as pore lining and kaolinite as pore filling. Illite also formed shards attached to the surface of a grain and extended to another making a bridge-like connection.

Kaolinite is a common authigenic mineral with relatively coarse crystals which are visible in thin section (Plate XII) and are identified readily by a scanning electron microscope. These crystals consist of a face-to-face stacking of plates referred to as booklets (Plate XIII). Kaolinite has very low birefringence except when it is stained by iron.

Chlorite is very variable in form. It occurs as rosettes (Plate XIV) or honeycomb. In thin sections chlorite pore lining is usually obvious due to its green color, especially

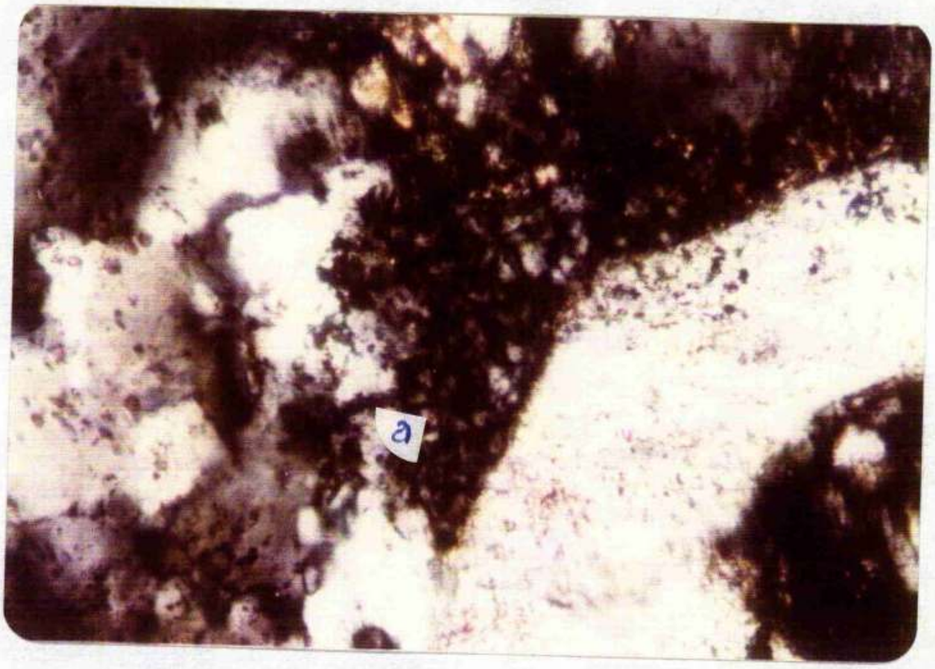


Plate XII - Thin section photograph showing authigenic kaolinite (a) filling a pore between quartz grains. 375X, 0-14 at 1700-1800 ft.

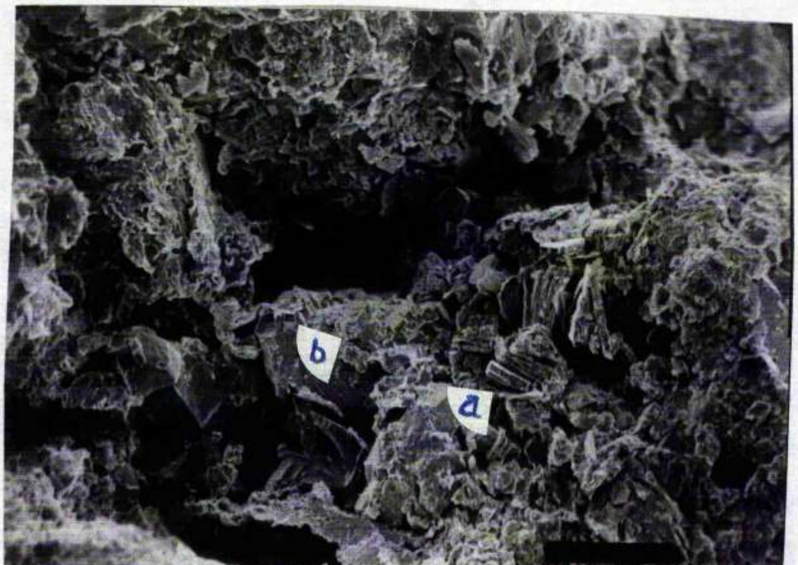


Plate XIII - SEM photomicrograph showing booklets of kaolinite (a) in pores and on silica overgrowth (b). 1000X, G-33 at 8495 ft.

if it is thick. Its occurence in the Taglu Member is limited.

Illite because of its higher birefringence is easy to detect in thin sections. It occurs as lath-like projections or as plates (Plate XV). It is the most common clay mineral in the Taglu sandstones.

The generally low percentage of authigenic clay minerals in the sandstones of the Taglu Member could be attributed to the presence of matrix between the sand grains (Wilson and Pittman, 1977). Samples with high matrix content are usually very low in clay content. ~~Grain-size seems to be another factor that controls their distribution~~. ~~The coarser the grains the higher is the clay content~~.

Order of Cement: From thin section and scanning electron microscopy it is revealed that carbonate cement may have been formed as either early or late. .. Dolomite ~~which originally was calcite or aragonite is observed~~, ~~in some pla~~ is, forming a rim around the primary grains. Siderite may have the same relationship. In some cases dolomite, siderite, and calcite are observed growing on crystals of other cementing material. Silica cement is almost always observed as an overgrowth on quartz grains. This type of silica cement must have been formed as an early cement because it grows directly on the grains which have not been compacted. However, in deeper boreholes where compaction is evident and pressure solution phenomenon is observed silica cement may have precipitated as a later cement.

Clay minerals such as kaolinite and chlorite may have been formed as an early or late cement. Under the scanning electron microscope kaolinite is observed to have grown over a quartz overgrowth or adjacent to it on the same grain in places where

Plate XIV - SEM photomicrograph showing rosettes of chlorite growing on the surface of the grain. 1000X, D-55 at 10409 ft.

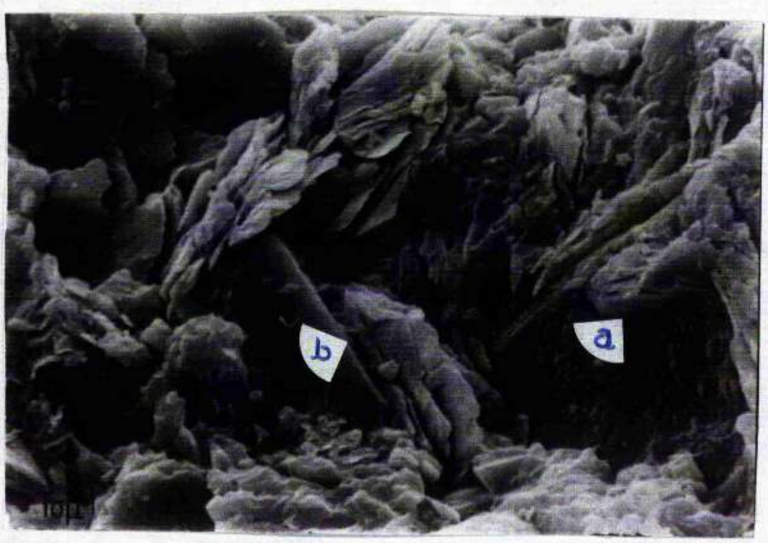


Plate XV - SEM photomicrograph showing lath-like projections of illite growing around quartz grains (a) and over the silica overgrowth (b). 1000X, 0-14 at 1470-80 ft.

no overgrowth is present. Where kaolinite is associated with chlorite the former is always formed over the latter. Chlorite is seen in thin sections as grain coating but samples viewed under the scanning electron microscope reveal chlorite forming over quartz overgrowth, suggesting that chlorite may have been formed as an early or late cement. Illite,on the other hand, is always present as crystals that grow on other cement.

CHAPTER VI

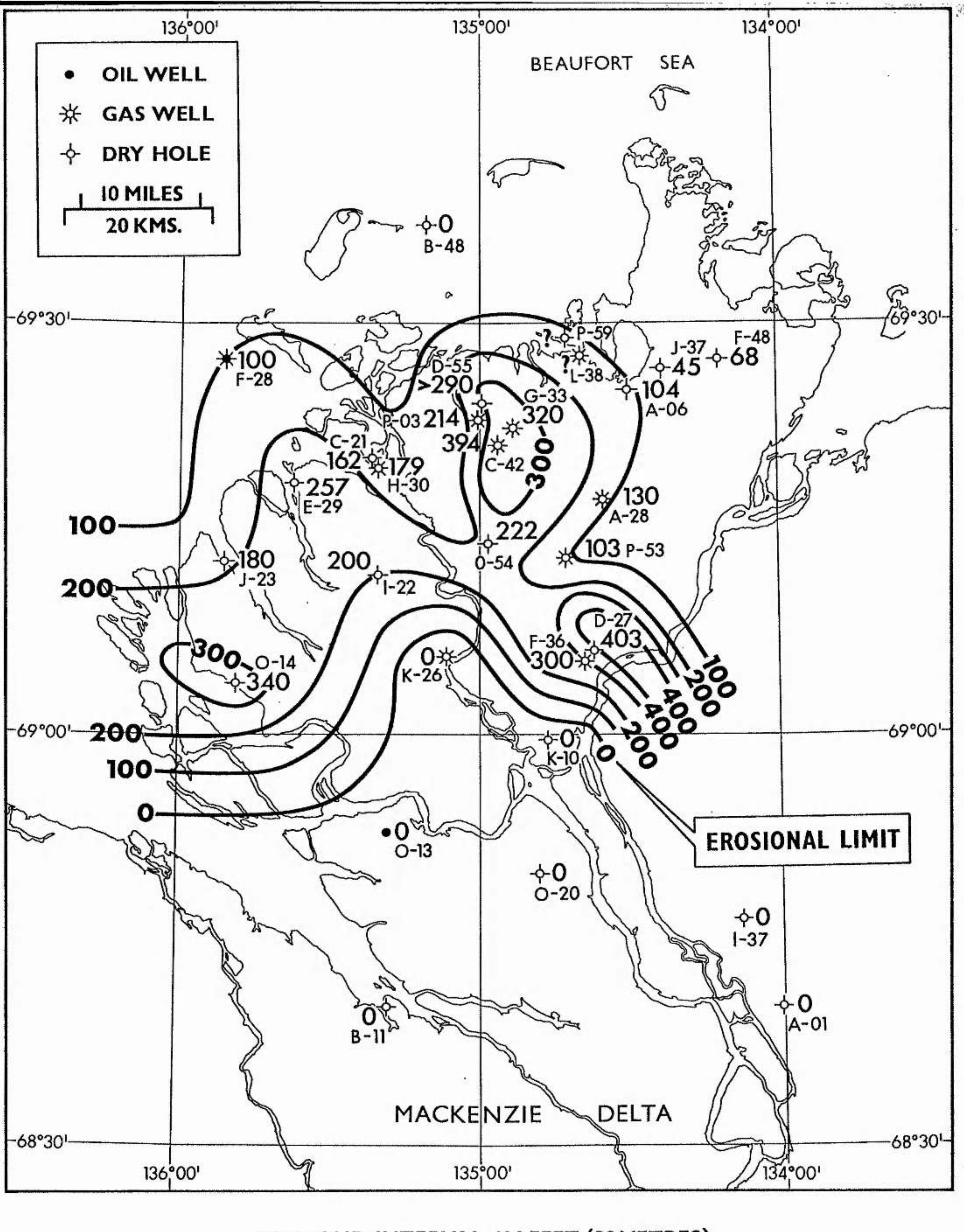
ENVIRONMENTS OF DEPOSITION

Available literature on the depositional environments of the Taglu Member or its equivalents is very scarce. Shawa et. al. (1974) interpreted the environment of deposition of the Taglu Member encountered in the Taglu G-33 borehole only. Bowerman and Coffman (1975) inferred the depositional environments of the Taglu and other underlying rock units in the Taglu Gas Field. The lack of documented and comprehensive studies on this member stems mainly from the difficulty of correlating it from one borehole to another.

The Taglu Member forms a sandstone wedge which depositionally thins in a northern direction (Fig. 23). The decrease in thickness is accompanied by a decrease in grain size and a change in facies from predominantly sandstone to predominantly shale.

The Eskimo Lakes Arch as well as the high Brooks Range and Richardson Mountains existed throughout the Paleogene (Young et. al., 1976) to the present. A marine basin was located at the northern edge of these structural elements (Young et. al., 1976; Lerand, 1975). This implies that the structural setting of the Mackenzie Delta has remained almost unchanged since the start of the Tertiary. On the evidence of pollen assemblages Staplin (1976) concluded that the climatic conditions during Eocene and Miocene times were temperate to cool temperate, considerably warmer than at present.

The Taglu Member in its type section is divided into two main sequences. The lower sequence consists of lithofacies "1" and "2" and the upper sequence consists of lithofacies "3"



CONTOUR INTERVAL: 100 FEET (30 METRES)

Figure 23 - Net sandstone isopach of the Taglu Member. CI = 100 ft

and "4" (Fig. 7). Each sequence shows a generally upward-coarsening cycle overlain by one or more upward-fining cycles of terrigenous material. The vertical changes in grain size can be observed on the gamma-ray log which corresponds very closely to grain size profiles as indicated in Chapter IV. Environments which each produces coarsening upward sequences are deltas (Fisk, 1955; Frazier, 1967; Fisher and Brown, 1972; Coleman and Galiano, 1964; and many others), off-shore bars or barrier islands (Bernard et. al., 1970). There are, however, several criteria that permit the distinguishing of deltas from off-shore bars and barrier islands. The upper part of a delta sequence shows evidence of a low-energy environment (Miall, 1976) and often deposition by distributary channels. On the other hand an offshore bar or barrier island frequently shows evidence of a high-energy environment (Miall, 1976) such as a beach or a shoreface and, in the case of a barrier island, the top of the sequence is eolain which is almost devoid of clays (LeBlanc, 1977). Moreover, delta deposits are rich in carbonaceous matter throughout, contain minor amounts of glauconite (Selley, 1975) and a few fossils. Offshore bars or barrier islands, on the other hand, are poor in carbonaceous matter, except in their lower part, rich in glauconite (Selley, 1975) and, generally speaking, contain more fossils than delta deposits. Growth faults and mud diapirs are associated with delta deposits and have not been reported in any other environment. This type of faults and the mud diapirs are associated with the Taglu Member in the research area.

Each of the two sequences in the Taglu type section represents a regressive phase overlain by a trangressive; from shale and silt to sandstone back to shale and silt. This vertical change within a sequence is characteristic of many deltas (Fisher, et. al., 1969; Gould, 1970; Wright and Coleman, 1973). The vertical change is also accompanied by a lateral change in facies from sand to shale as can be seen on any down dip section through any deltaic deposit. The Taglu Member shows this lateral change in facies (Fig. 23).

The characteristic features discussed above strongly suggest the presence of a deltaic deposit in the type section of the Taglu Member as well as in the general research area. Scruton (1960) and Coleman and Gagliano (1964) indicated that two main phases can be distinguished in deltaic deposits. One is constructional and located in the lower part formed by the progradation of land-derived sediments and the other is destructional making up the upper part of the delta. The latter phase is the product of reworking by waves, tides, storms or other currents within the depositional basin. In the Taglu G-33 only the constructional phase is observed. This suggests that the deltaic deposit of the type section is fluvially dominated and that marine influence is minor. According to Fisher (1968, 1969) a fluvially dominated delta is to be classified as highly constructional.

Highly constructive deltas produce a lobate or elongate delta morphology. The prograded lobes of a delta with a high sediment influx such as the Mississippi form in deeper water. The weight of the sand deposited in the prodelta on thick mud causes compaction of the mud and triggers the formation of mud diapirs (Morgan et. al., 1968) and growth faults (Bruce, 1973; Dailly, 1976). In shallower water where mud is relatively thin the deposited delta sand is more susceptible to wave action or storms between flood times and part of it could be worked by marine processes forming thin beach or strand line deposits. The energy level of the basin controls this minor destructive phase in the highly constructive delta. Sandstones are the skeletal framework of a deltaic deposit, therefore, net sandstone maps provide a true picture of delta morphology. Figure (23) which shows the distribution of net sandstone thickness suggests that the Taglu Delta belongs to the elongate type. Two elongated lobes are mapped in the vicinity of G-33 and E-29 boreholes.

Barell (1912) defined a delta as a deposit partly subaerial and partly subaqueous, built by a river into a body of water. For the sake of simplicity the subaerial part will be referred to in this research as the upper delta and the part under water as the lower delta. The upper delta contains distributary channels, splay deposits, and interdistributary bays or marshes. The lower delta contains distributary mouth bars and the prodelta. The following are the environments with the deltaic deposit that are represented in the Taglu Member. These environments are referred to in figures 24 through 31 for the boreholes along the geologic cross-sections and the rest are listed in Appendix C.

Distributary Channel Deposits

These deposits are the product of highly constructive deltas (Fisher _et_. _al_., 1969). They are formed by streams with large quantities of suspended sediments rich enough in mud and silt to construct levees (Brown and Fisher, 1976). The sand is transported in the distributary channel as bed load, hence channel deposits are very similar to fluvial deposits, and in places

Fig. 24 Stratigraphic Section Reindeer D-27
(for symbols see Fig. 20)

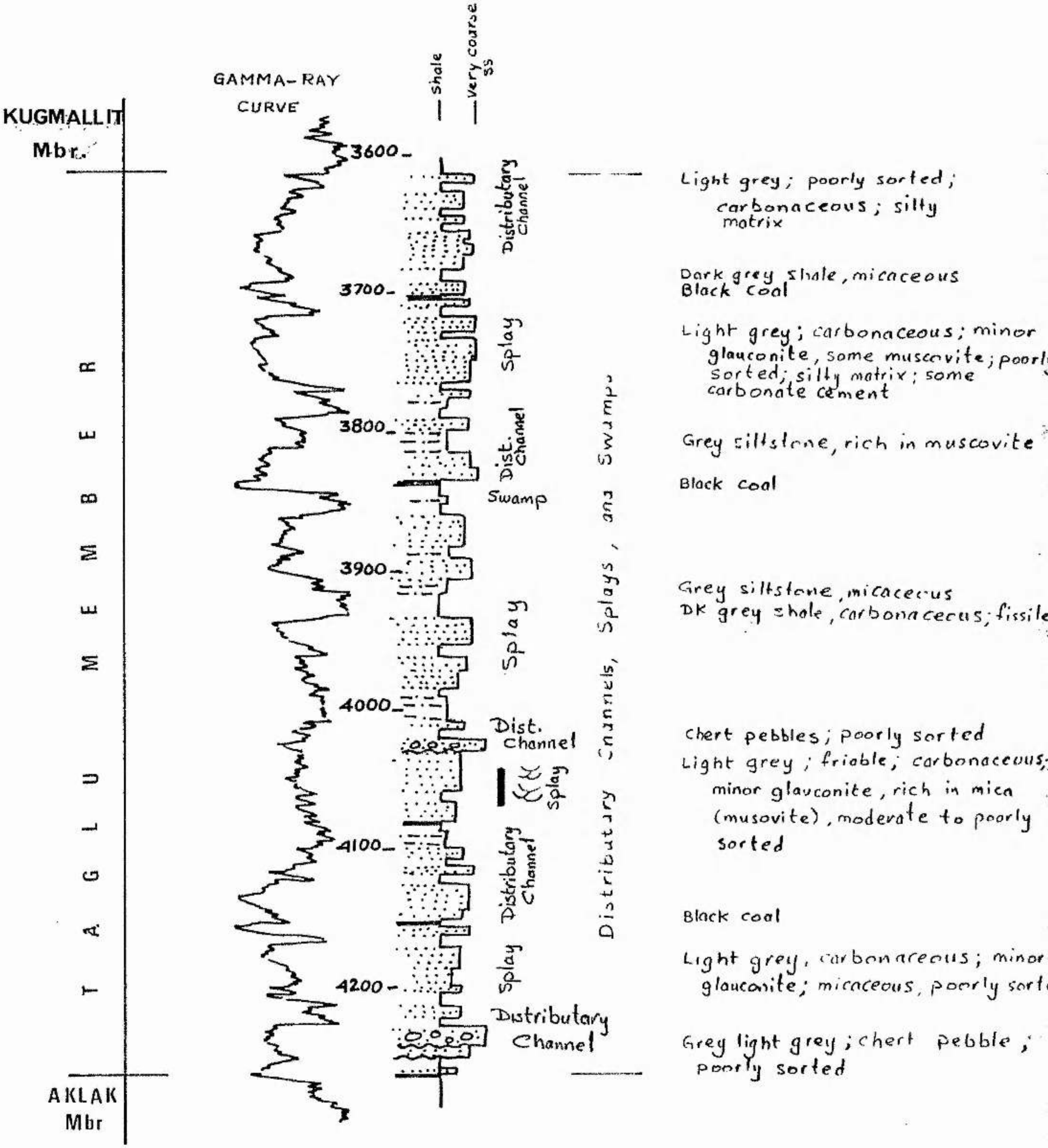


Fig. 25 Stratigraphic Section Ya Ya P-53
(for symbols see Fig. 20)

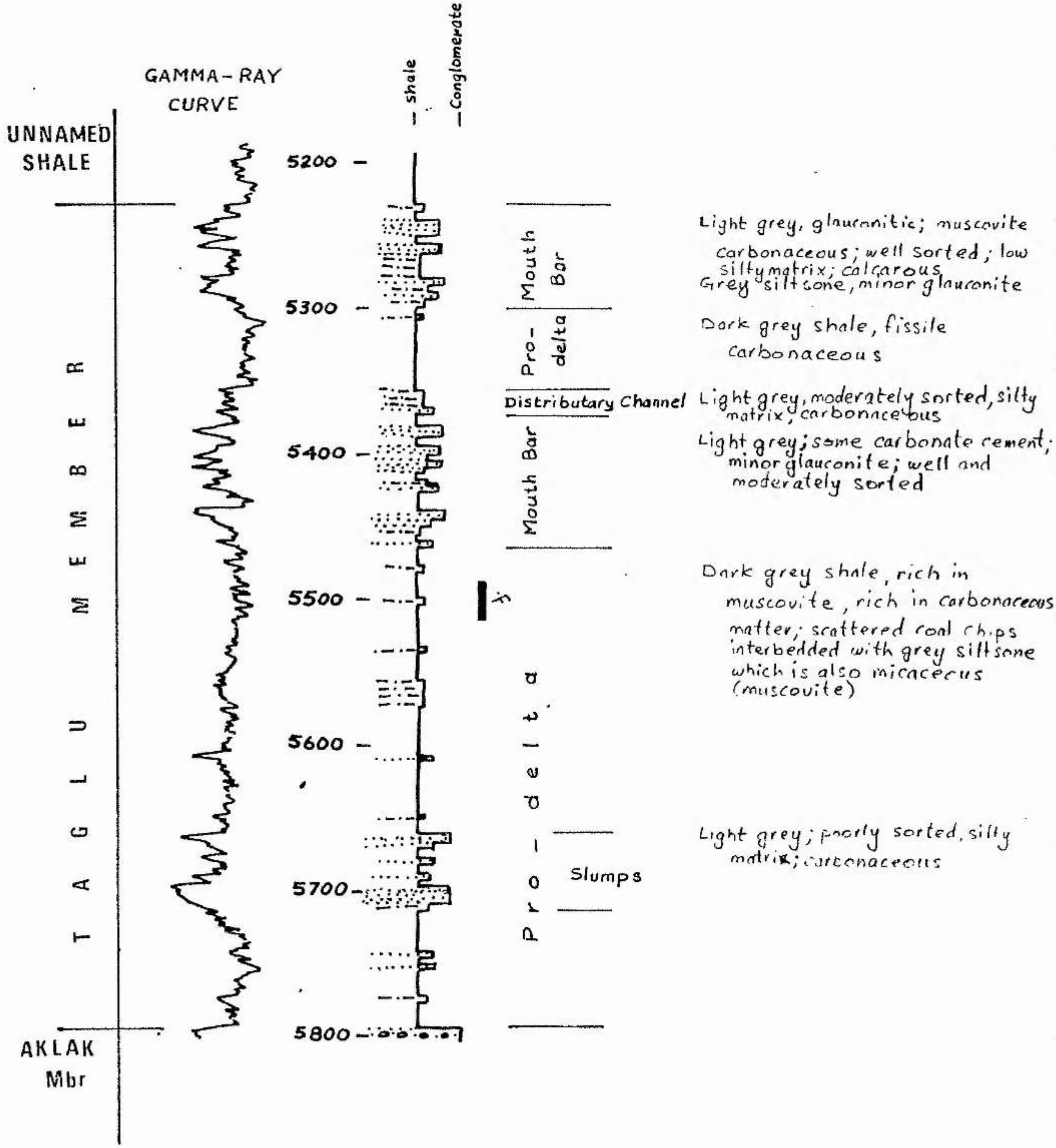


Fig. 26 Stratigraphic Section Taglu P-03
(for symbols see Fig. 20)

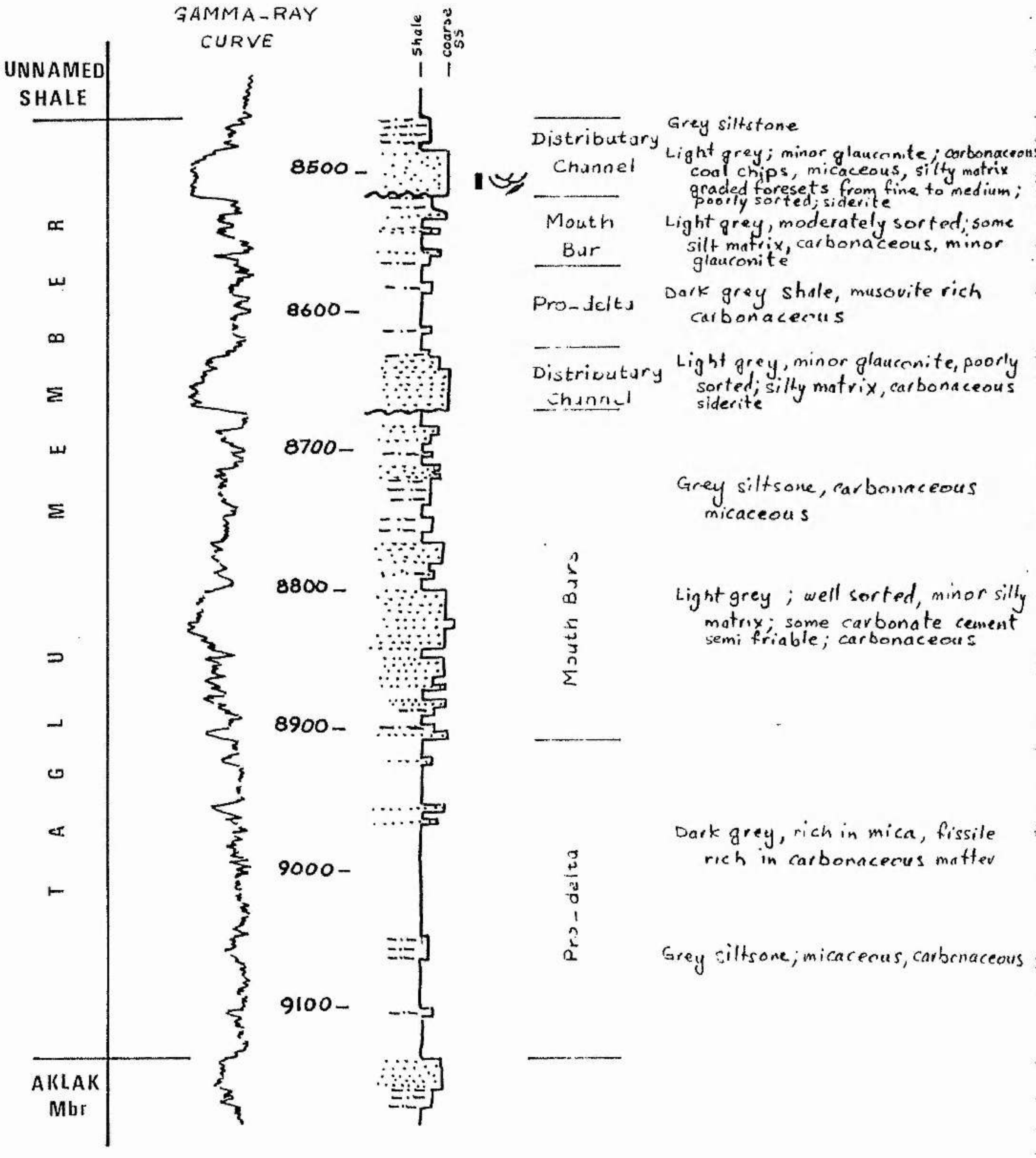


Fig. 27 Stratigraphic Section Unipkat I-22
(for symbols see Fig. 20)

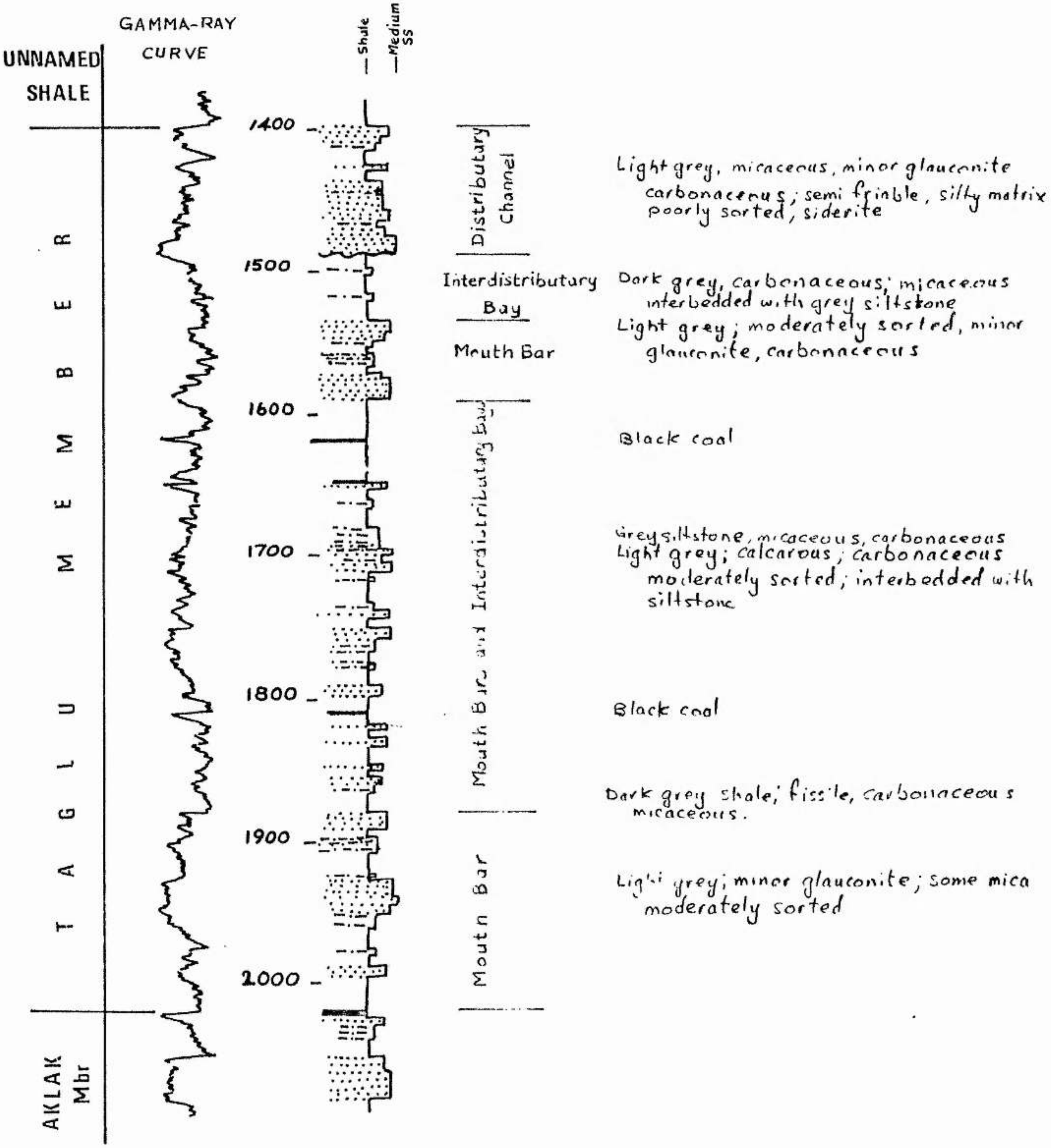


Fig. 28 Stratigraphic Section Langley E-29
(for symbols see Fig. 20)

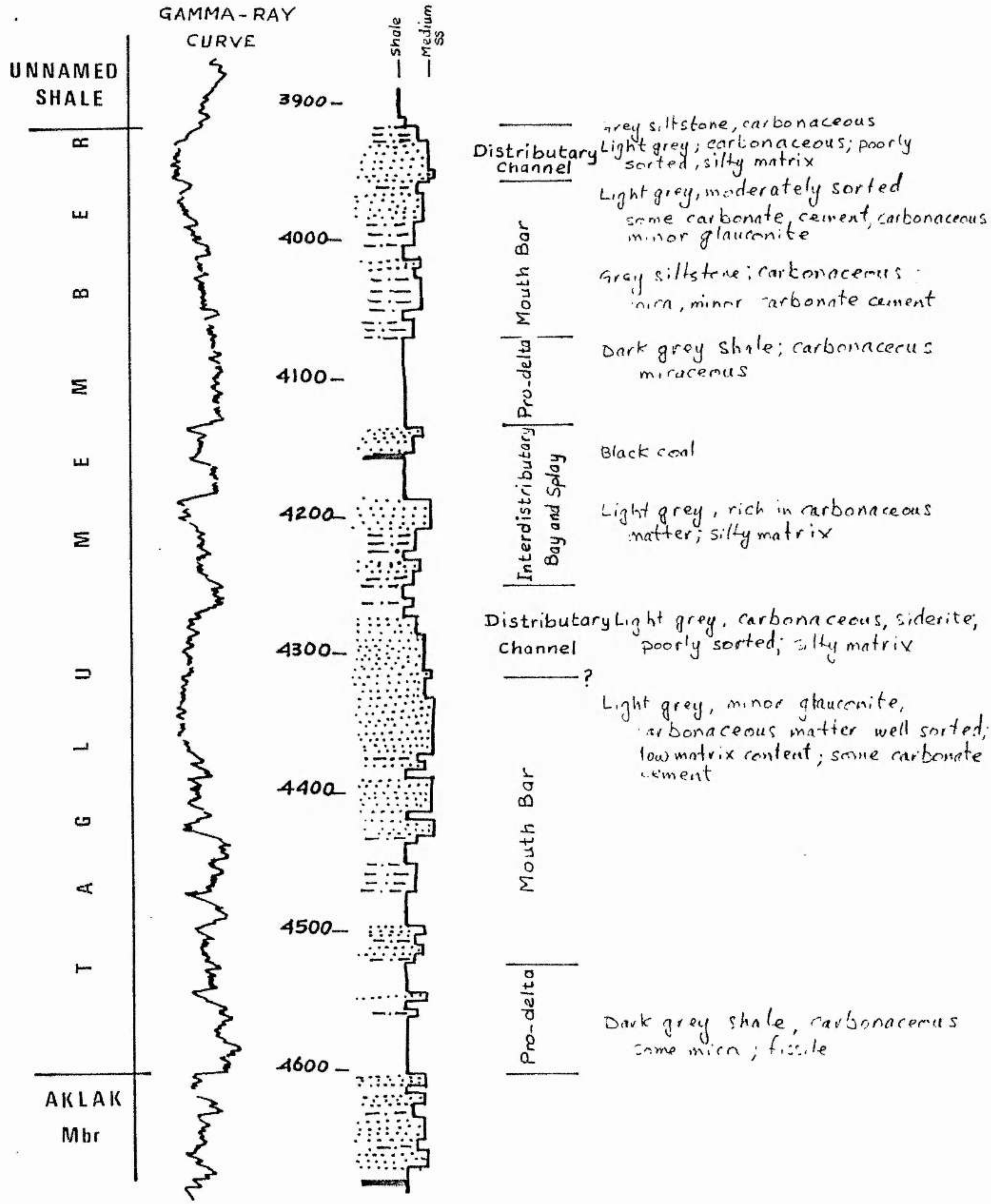


Fig. 29 Stratigraphic Section Adgo F-28
(for symbols see Fig. 20)

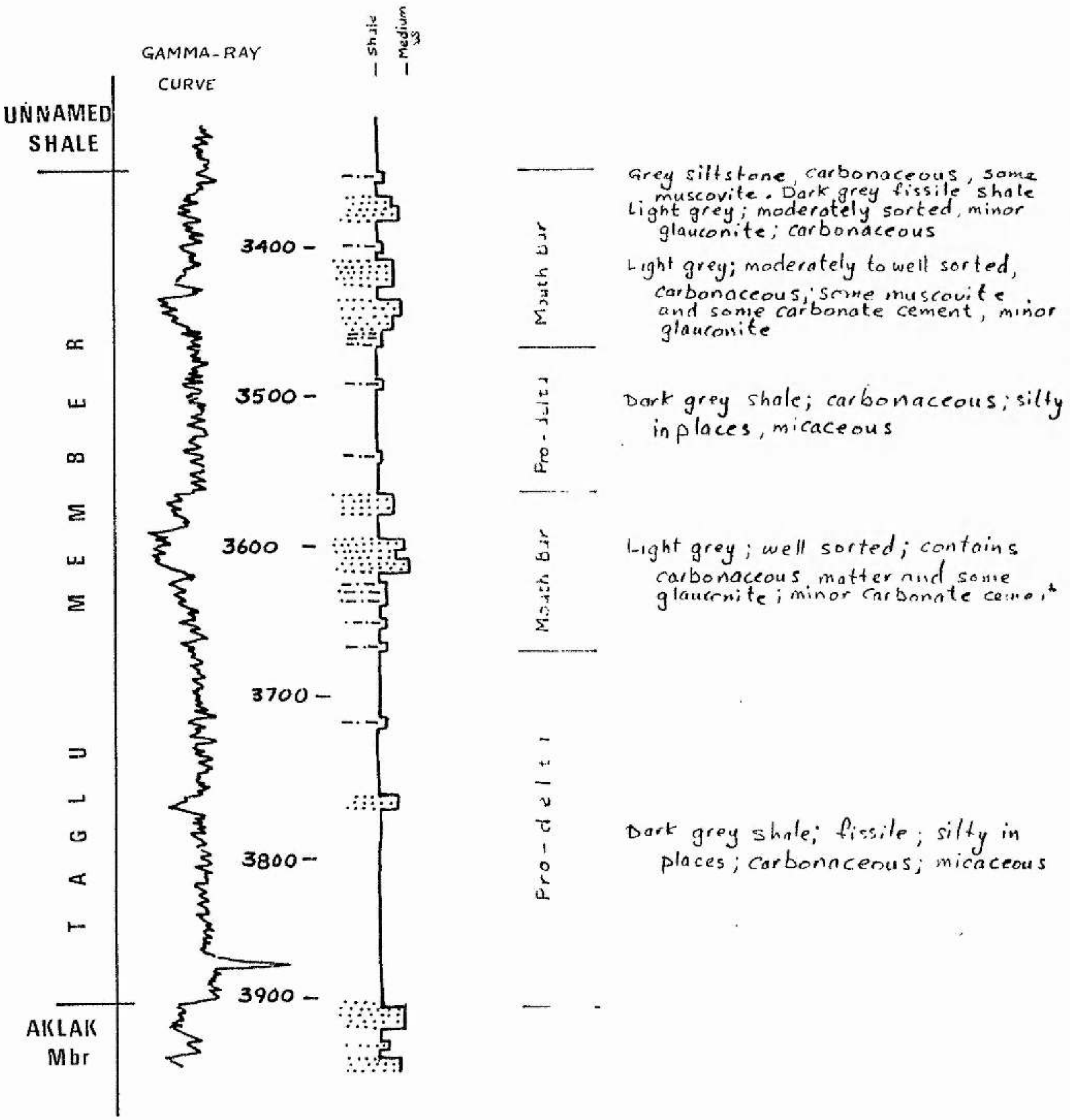


Fig. 30 Stratigraphic Section Ellice O-14
(for symbols see Fig. 20)

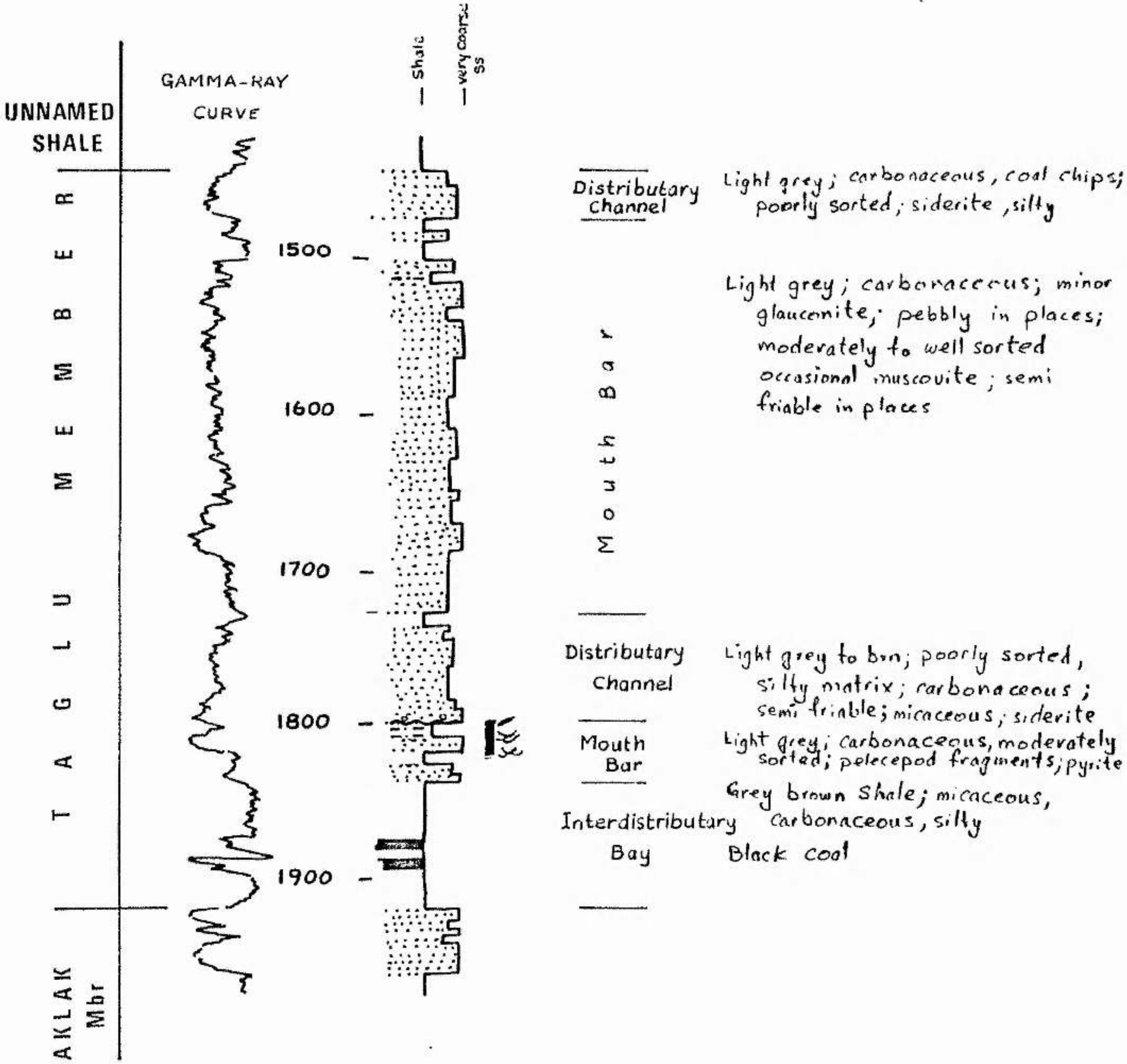
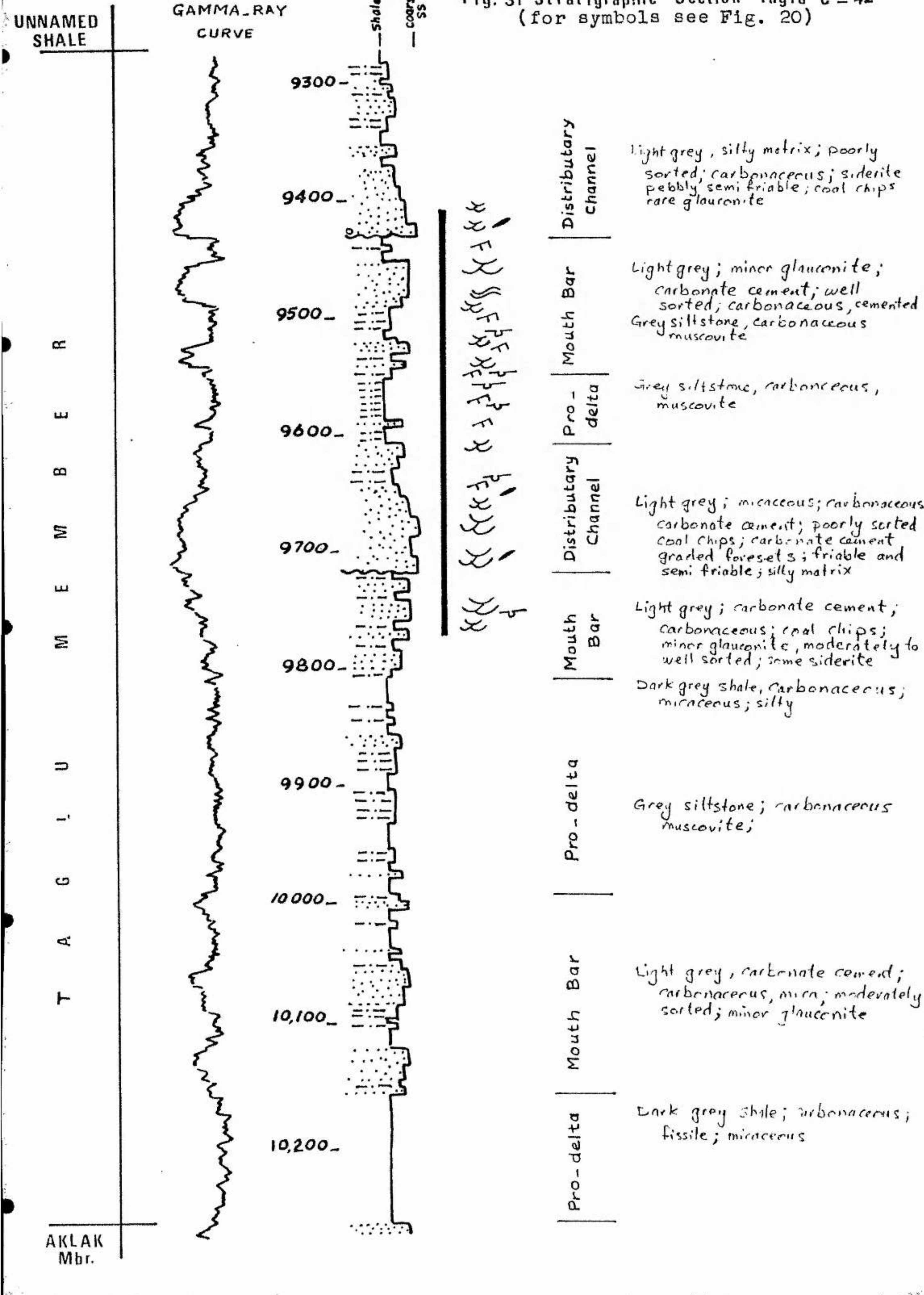


Fig. 31 Stratigraphic Section Taglu C - 42
(for symbols see Fig. 20)



even percussion marks are present on the pebbles (Plate XVI) found in them. But the process of deposition is of much shorter duration than that of fluvial channels due to gradual channel subsidence. Fisk (1955), Frazier (1967), Fisher and Brown (1972) described distributary channel deposits in detail. These usually have an erosional (Plate XVII) or very sharp lower contact and exhibit a fining upward or a uniform grain-size sequence. The sandstone of the deposit is, generally speaking, poorly sorted and may contain minor glauconite. An ideal sequence consists, in ascending order, of trough cross-beds on medium scale that contain rip-up clasts; occasionally convolute laminations are present and overlain by trough cross-beds on a smaller scale as well as tabular cross-beds. Ripple drift cross-laminations are sometimes overlain by levee deposits of shale and siltstone. Occasionally, channel-fill, laminated mud rich in organic matter is deposited in abandoned channels and are found on top of the sequence. This environment is represented in several boreholes in the research area (Fig. 24 through 31 except Figure 29) also see Appendix C.

Interdistributary Bay and Marsh

Interdistributary bay and marsh consist mainly of clay and silt with occasional fine sand brought to the site of deposition by suspension during flood time. The sediments of this environment are very rich in carbonaceous matter. If the interdistributary bay and marsh is poorly drained as is mostly the case and if the climate is relatively wet, carbonaceous matter accumulates in such a reducing environment and forms coal. If

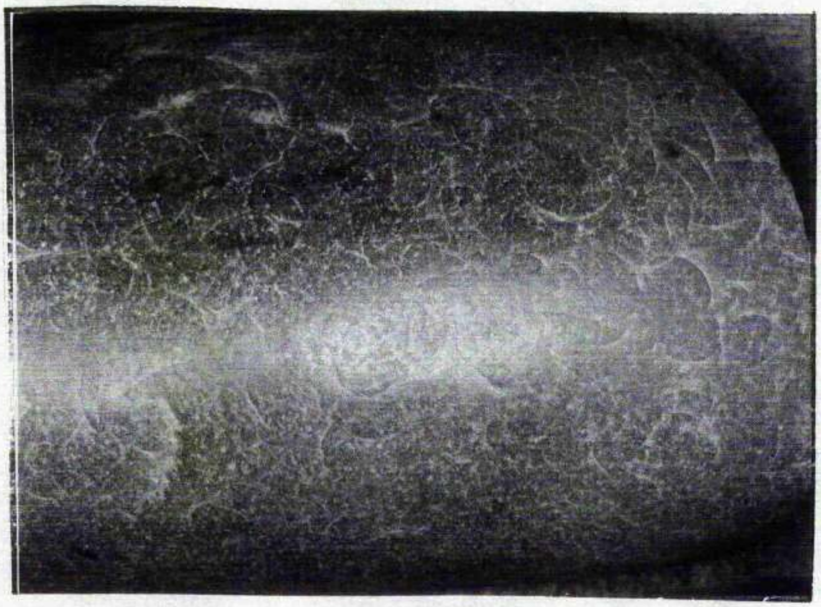


Plate XVI - Percussion marks on a chert pebble. Core photograph scale 1:1, C-42 at 9434ft.

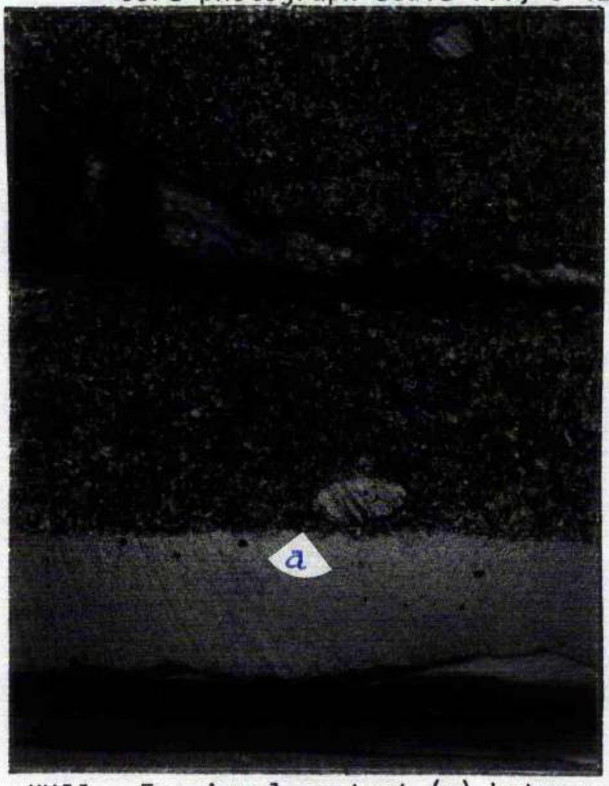


Plate XVII - Erosional contact (a) between pebbly coarse-grained sandstone and an underlying fine-grained sandstone unit. Core photograph scale 1:1, G-33 at 8227 ft.

they are well drained an oxidizing environment prevails and no coal is deposited. Quite often a splay deposit forms in the interdistributary or marsh environment. The splay which exhibits an upward coarsening grain-size sequences resembles closely a deltaic deposit on a very small scale but often lacks distributary channel sediments. The splay is formed in front of a crevasse which is a cut through the levee that starts during flood time. When the distributary channel exceeds its maximum capacity the water spills over the levee and in some places cuts it down. The water carries a large load of suspended sediments especially in the upper column of the water. These suspended sediments are deposited first in the bay or marsh environment. As channel water progresses in cutting the crevasse deeper more coarser sediments are brought and deposited above the finer which are characteristically rippled. This produces an upward coarsening cycle of poorly sorted sediments rich in clay or silt matrix and lack bioturbation. When the flood stage ends the splay deposit stops growing, allowing silt and clay to be deposited on top of it. Splay deposits are often underlain or overlain by coal if the climate supports lush vegetation. Gas heaving structures could also be found in these sediments if biogenic gas is produced from the decaying carbonaceous matter. This environment is represented in several boreholes (Fig. 24, 28, 30) also see Appendix C.

Distributary Mouth Bar

The sand transported by the distributary channel is deposited near the channel mouth where it forms a mouth bar. In a highly constructive delta only a minor portion of this sand is redistributed by marine processes. The sand/shale ratio is normally high in this environment and the sand could attain a thickness measured in hundreds of meters depending on the size of the distributary channels and the rate of subsidence in the basin. The sand of a mouth bar which generally shows an upward coarsening in grain size and contain minor glauconite is usually clean and well or moderately sorted with a minimum of clay and silt matrix making it an excellent hydrocarbon reservoir. Basinward this sand becomes fine-grained exhibiting ripples (Plate XVIII) and grades into silt and clay which are rich in carbonaceous matter. The outer limit of this environment produces slump structures and convoluted beds and often it is bioturbated (Plate XIX).

The process of deposition of the mouth bar sand occurs both by lateral transport and by settling from suspension when wanning currents enter the basin. Therefore, dominant sedimentary structures are here cross-beds and graded beds (Plate XX) if marine processes are at minimum. Stratification in the mouth bar sand is on medium or large scale, but basinward it is on a smaller scale. In places mud diapirs penetrate through the mouth bar sand and in some cases even penetrate through the overlying distributary channel deposit. The presence of prodelta mud underneath the mouth bar sand combined with loading can lead to faults or contorted bedding (Plate XXI). As deltas prograde seaward distributary channels advance and cut the mouth bar deposit sometimes down to the prodelta mud. River mouth bars coalesce to form an extensive subaqueous sand sheet in front of the delta. This environment is represented in several boreholes (Figs. 25 through 31) also see Appendix C.

Plate XVIII - Core photograph showing ripple cross-lamination fine-grained sandstone. Scale 1:1, C-42 at 9442 ft.

Plate XIX Boiturbation in fine-grained sandstone and siltstone. The burrows are near vertical. Core photograph scale 1:1, C-42 at 9504 ft.

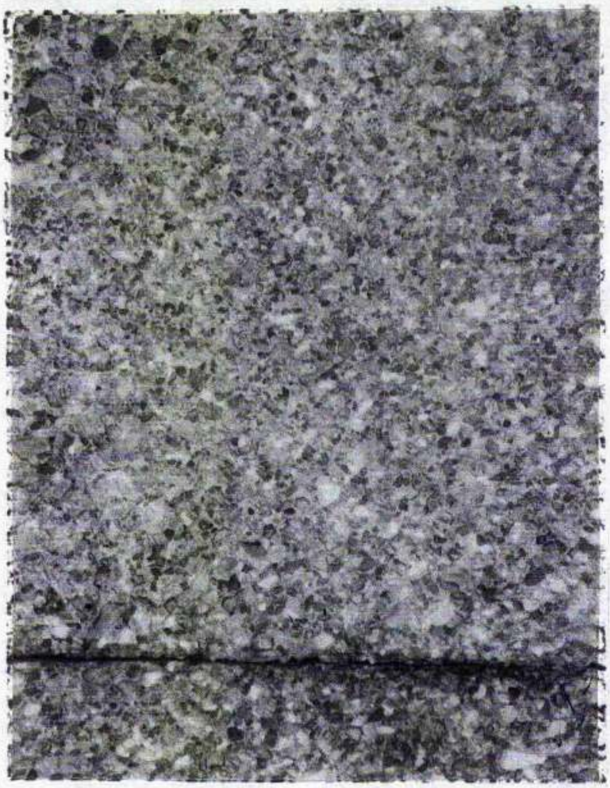


Plate XX - Core photograph showing graded beds from very coarse-to medium-grained sandstone. Scale 1:1, C-42 at 9714 ft.

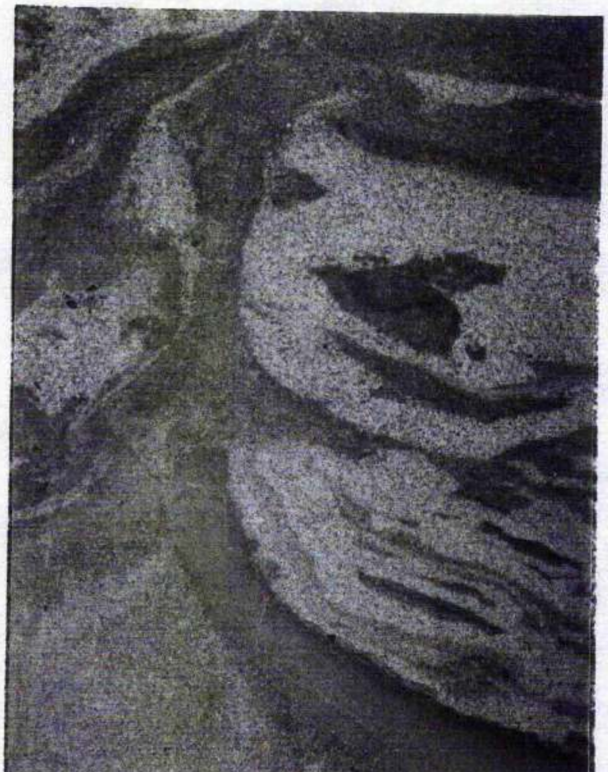


Plate XXI - Contorted beds as shown in a core. This deformation may have resulted from water escape due to compaction or gas escape, both while sediments were soft. Scale 1:1, C-42 at 9497 ft.

Culmulative curves of grain-size were obtained from disaggregated core samples and plotted on probability paper as an extra tool for environmental interpretation. This method of reading grain-size cumulative curves was publicized by Visher (1969). Based on empirical results it is generalized that each major sedimentary environment produces similar-looking cumulative curves. But the cumulative curves which were obtained from several deposits within the Taglu Member did not always produce similar-looking curves from the same environment (Figs. 32 and 33). Where the sedimentary structures and grain-size differ within a given environment the shape of the curve differs too.

Professor E.K. Walton, Dr. W.E. Stephens, and on some occasions myself investigated a number of models on grain-size cumulative curves. It was concluded that it is difficult and often impossible to infer sedimentary processes or/ some environments from cumulative grain-size curves (see fig. 32).

Taglu Depositional Basin

A complete deltaic sequence represents all of the environments discussed above starting with distributary channels on top and ending with pro-delta mud. The contacts between the lithofacies of a deltaic deposit are always gradational except the lower contact of the distributary channel. As a delta reaches its culmination due to exhaustion of its sediment supply or a shift in the river which supplies the sediments, the deltaic deposit subsides partly under its own weight and by continuous regional tectonic movements. When this happens marine water advances over the deltaic sand and deposits shelf sediments on top of them. Often another deltaic sequence is deposited on

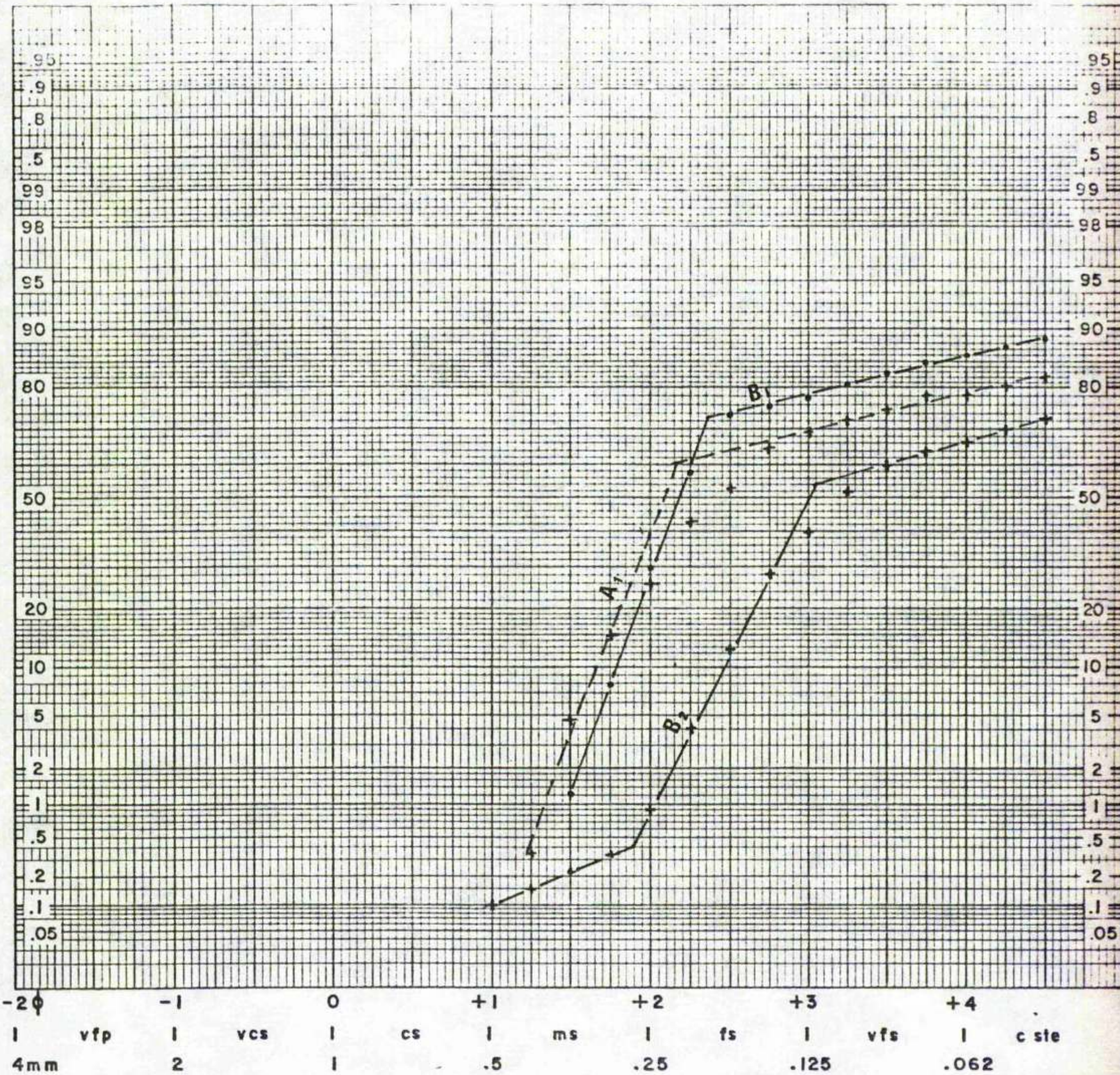


Figure 32 - Cumulative segmented curves representing samples from the Taglu sandstone. (A) are samples from distributary channel, and (B) from mouth bar deposits. A1 samples is from G-33 at 8194 ft., B1 from C-42 at 9454 ft., and B2 from G-33 at 8482 ft. Notice similarity of curves A1 and B1.

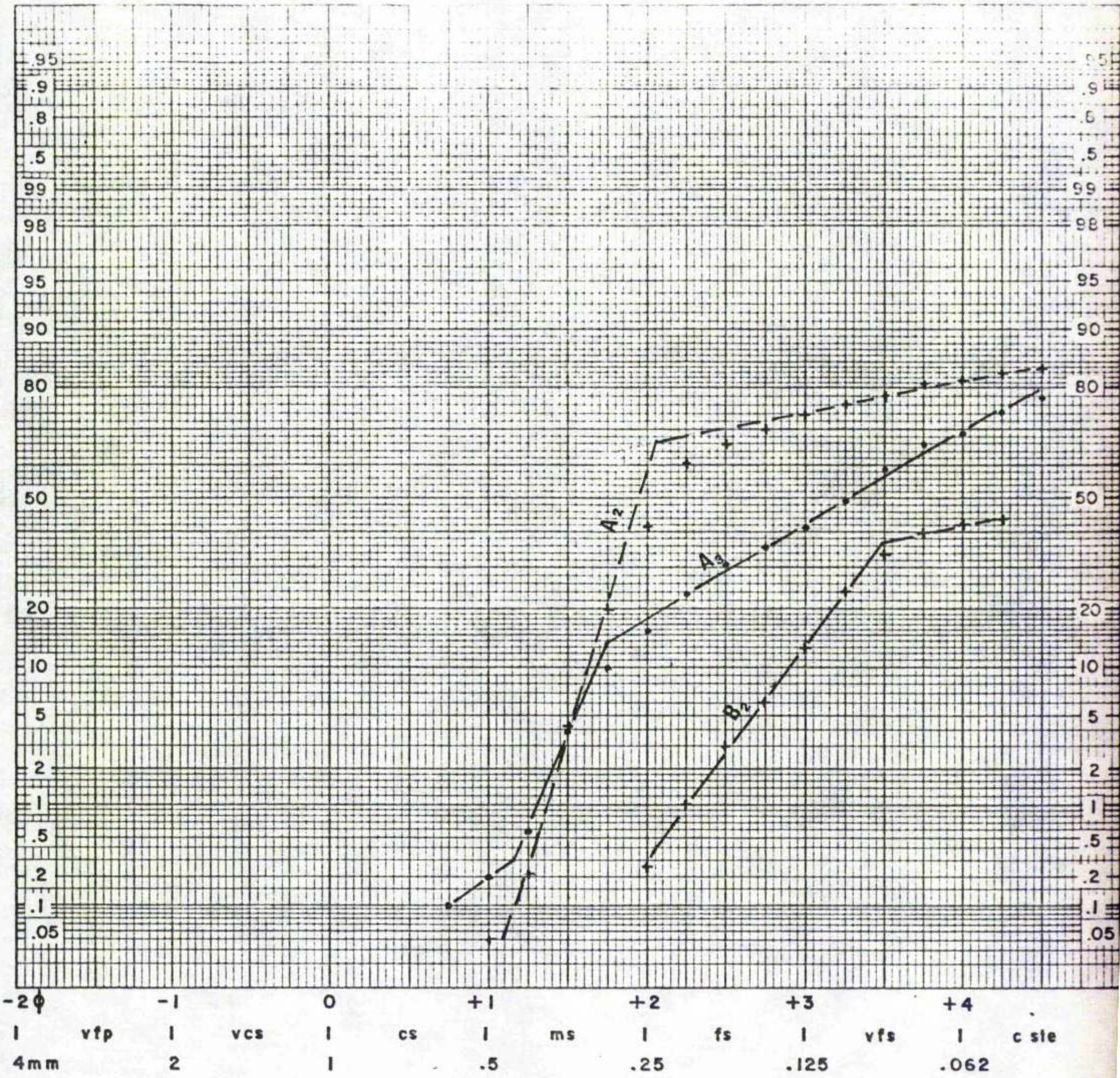


Figure 33 - Cumulative segmented curves representing samples from the Taglu sandstone (A) are samples from distributary channel, and (B) from mouth bar deposits. A2 sample is from G-33 at 8178 ft., A3 from G-33 at 8391 ft., and B2 from C-42 at 9474 ft. Notice the dissimilarity of A2 and A3.

top of a previous one (Coleman and Gagliano, 1964).

Two such sequences are present in the Taglu Member. One sequence consists of lithofacies "1" and "2" and the other of lithofacies "3" and "4". Each sequence represents an approximate time interval.

Sandstone thicknesses of as much as 50 ft. (15 m), without shale breaks, that exhibit trough cross-beds on a medium scale and that have sedimentation units with a minimum thickness of two feet (0.6 m) and do not show many erosional contacts suggest a continuous sediment influx during the deposition of the Taglu Member. The thickness of the individual lithofacies which in places reaches about 400 ft. (122 m) also indicates that the rate of influx in the lower sequence was relatively high. This is also supported by the presence of near vertical burrows (Plate XIX) ~~produced by organisms which kept pace with the high rate of sedimentation~~. Deltas with a high rate of sediment influx are fluvially dominated.

Cross-section (Fig. 34) shows that gross thickness of the Taglu Member does not change appreciably between D-27 and P-03 boreholes. It also shows that the pro-delta and the mouth bar environments attain a considerable thickness which indicates that the basin was continuously but moderately sinking. The underlying coal rich Aklak Member was interpreted as paludal and partly upper delta by Young et. al. (1976) and the overlying Taglu Member is prodelta and delta front in its lower part. This suggests that moderate subsidence occured after the deposition of the Aklak Member. The fact that there are two deltaic sequences within the Taglu Member in several boreholes further suggests moderate subsidence during the deposition of the first

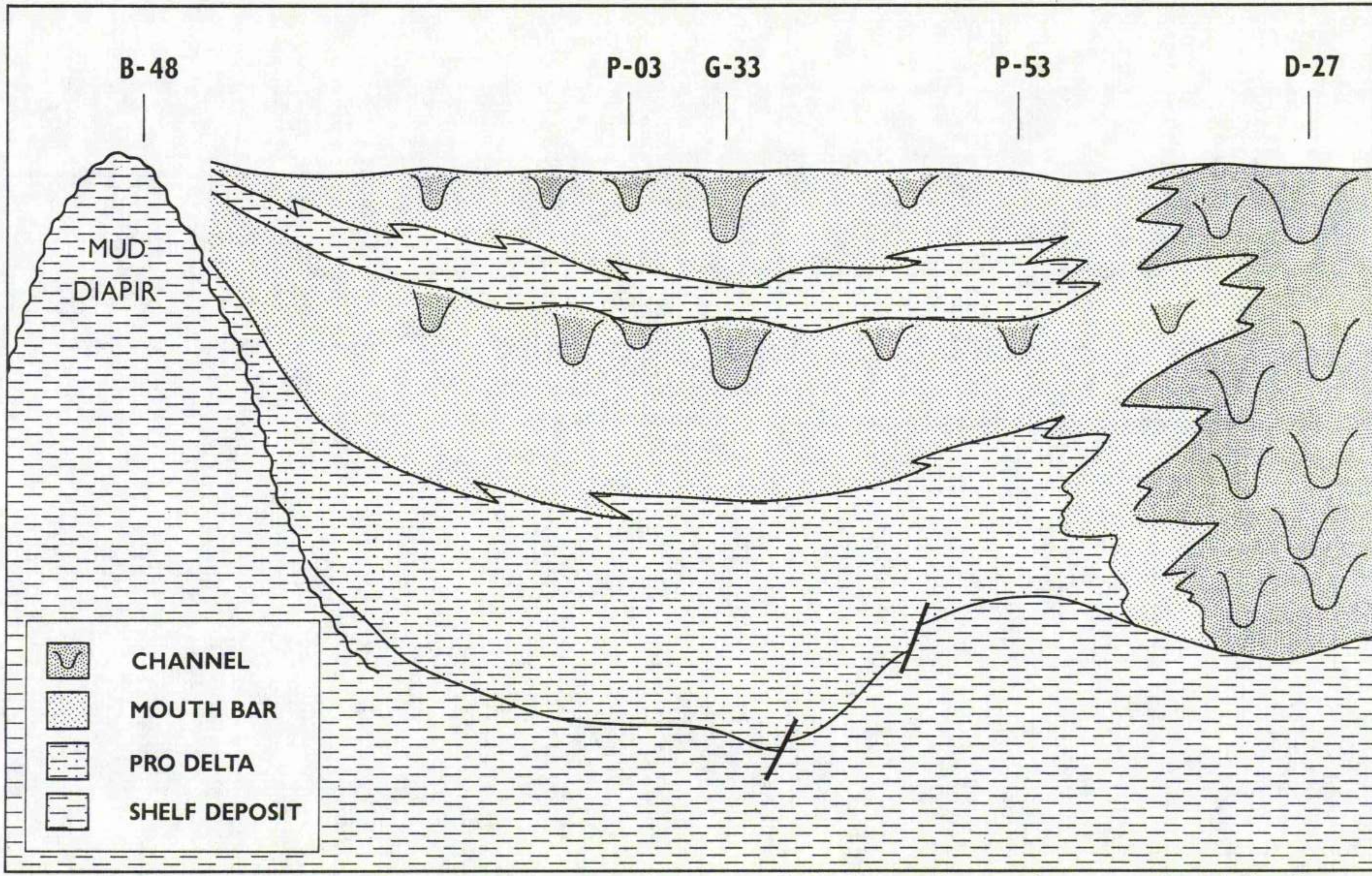


Figure 34 - Generalized cross-section based on actual Taglu environments encountered in the boreholes. It suggests that a moderate subsidence took place in the basin during deposition of the Taglu Member. Vertical scale is proportional to true thickness. For details see figures 7,24,25, 26.

Taglu sequence to permit deposition of the second (Fig. 7). The rate of subsidence was high during the deposition of lithofacies "1", low during the deposition of lithofacies "3" as indicate by their thicknesses. But the fact that the "unnamed" shale is marine strongly suggests that the basin continued moderate subsidence after Taglu deposition. Moderate subsidence and relatively high influx of sediments prograde a delta basinward for a long distance. This was demonstrated through a model constructed by Weimer (1961) where he illustrated that rate of subsidence was slightly less than the degree of sediment progradation but less than the rate of deposition. His model ranges in thickness from 1000-3000 ft. (304-914 m). In another depositional model constructed by Brown (1969) for a slowly subsiding basin, illustrated that rate of subsidence is much less than the degree of sediments progradation and also less than rate of deposition. His model ranges between 100-300 ft. (30-91 m) and the sequence is underlain and overlain by marine limestone.

Provenance

A general decrease in the Taglu grain size toward the north coincides with a decrease in its sandstone thickness and a change in lithofacies from predominantly fluvial to predominantly marine as shown on the stratigraphic sections (Figs. 25 through 31). This suggests that the source area of the Taglu sediments was somewhere to the south or southeast. Figure 16 shows that the trace-element content of Taglu G-33 and YaYa P-53 on one hand and Langley E-29 and Niglintgak H-30 on the other, differ greatly. The Taglu Member was deposited in the same general environment in all these areas. Ignoring possible effects of diagenesis, variation in trace-element composition must be the result of contribution from different source. Compositional triangles (Figs. 35, 36) show that the Taglu Member consists mainly of chert and quartz in some boreholes and predominantly of quartz in others. This could suggest that the two sources which contributed, at least in part, to the sediment-budget were the Richardson Mountains where chert is abundant and the Eskimo Lakes Arch with its sedimentary core where quartz is abundant. These source areas, are situated to the south and southeast of the research area (Fig. 4). Occasional presence of volcanic rock fragments may indicate that a third sediment source, possibly well to the south, is not excluded.

The occurence of coarse-grained sediments in the Taglu Member indicates transportation by high gradient river systems and/or a relatively short distance transport. The composition of the conglomerate is predominantly chert which might have been transported from Richardson Mountains.

The presence of coal in the upper part of the Aklak Member

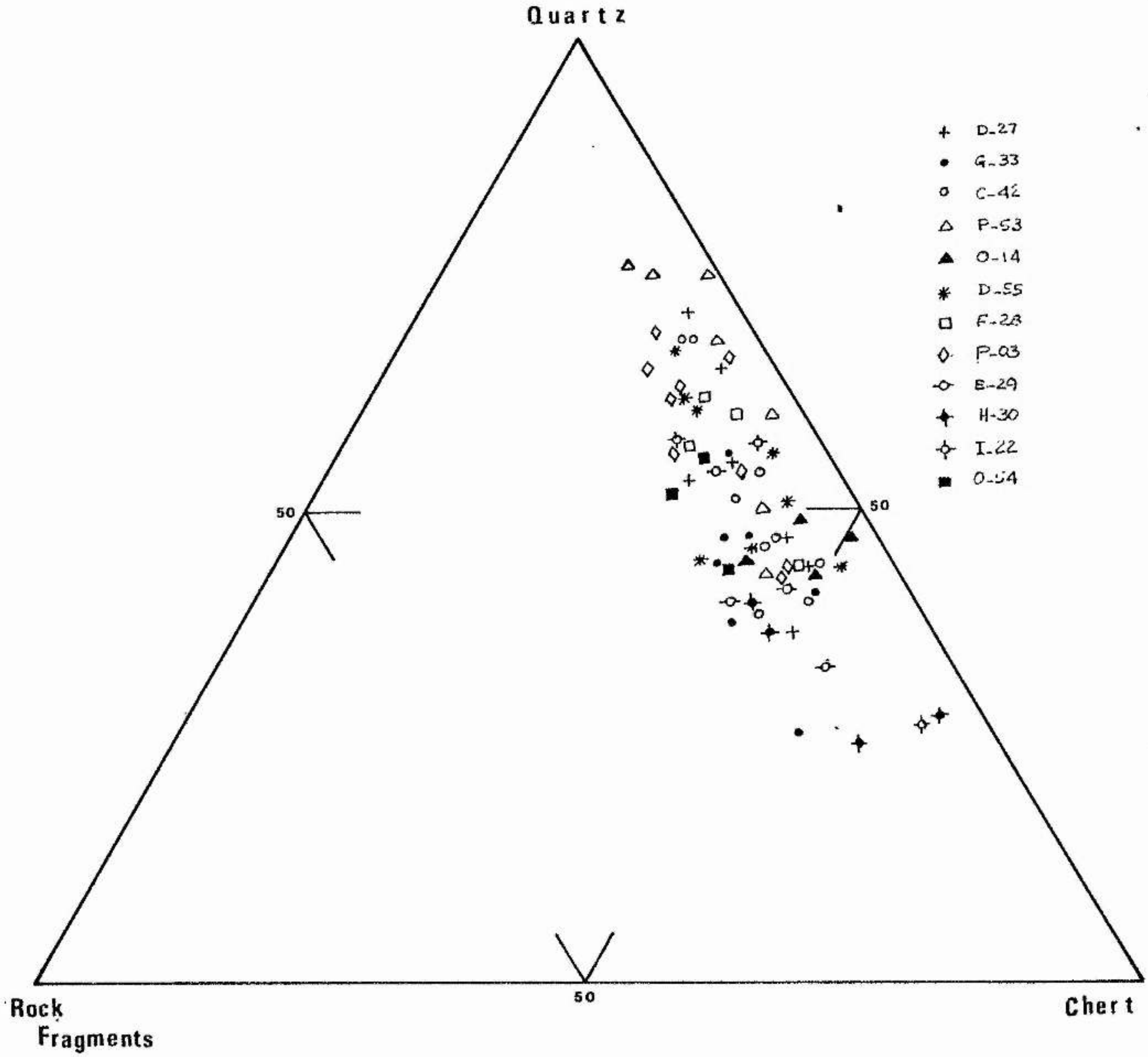


Figure 35 - Compositional triangle showing the distribution of three main constituents in the Taglu Member.

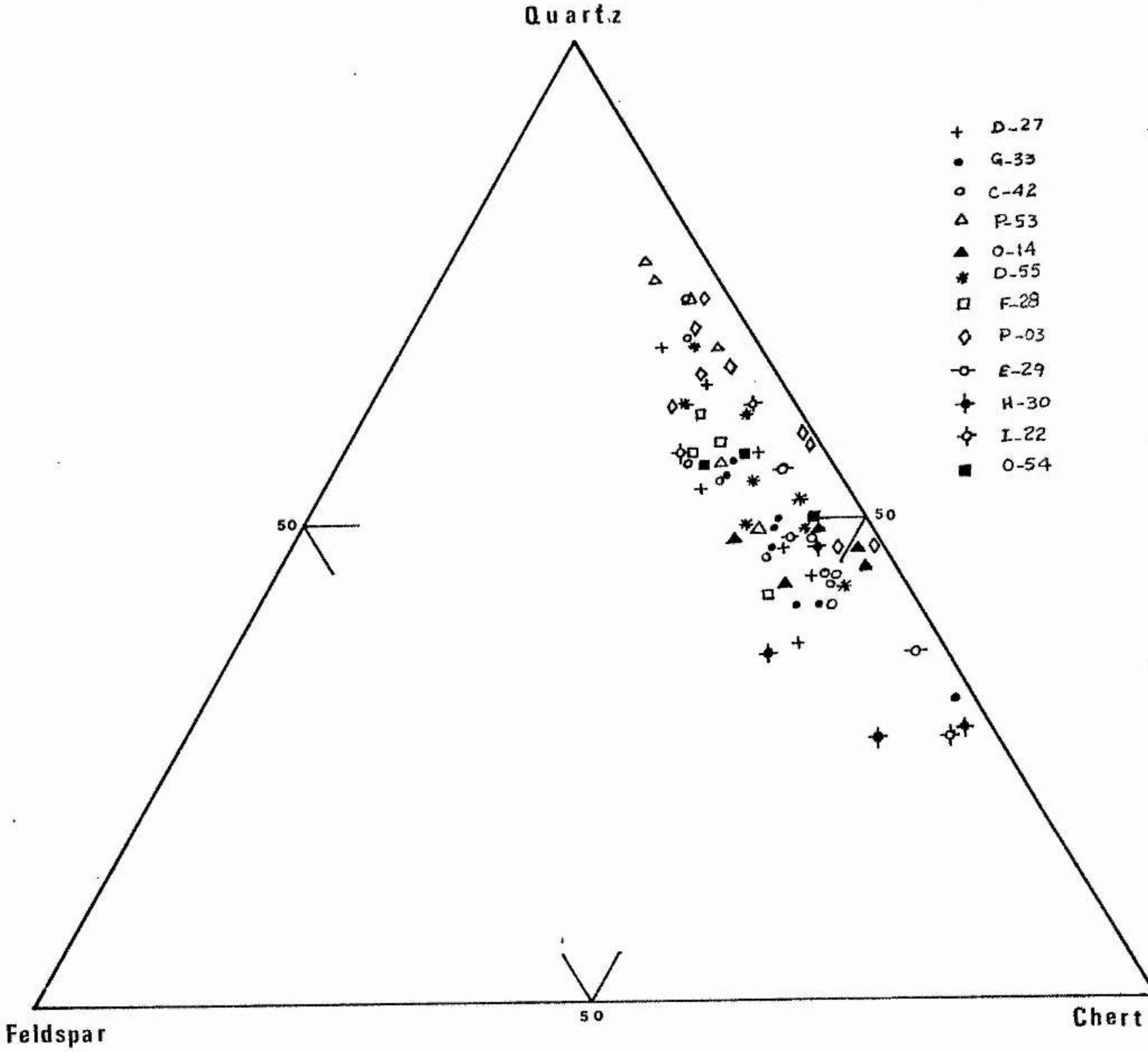


Figure 36 - Compositional trangle showing the distribution of three main constituents in the Taglu Member.

and its occasional presence in the Taglu Member implies lush vegetation and an abundance of moisture. Presence of minor hematite coating of grain indicates absence of warm tropical climate. Hematite precipitates authigenetically from the oxidation of iron released from iron-bearing minerals (Walker, 1967). NaCl or possibly zeolite, is observed on some sand grains (Plate XXII) in a couple of samples. This may indicate that minor evaporation of marine water may have taken place suggesting a warm temperature climate during or immediately after the depositon of the Taglu sediments. Trace elements analysis was not conclusive enough to determine the paleosalinity.

From the above discussion one would conclude that a cool but occasionally warm temperate climatic condition prevailed during the deposition of the Taglu. This conclusion is further supported by Staplin (1976) who suggested, as based on pollen evidence, that a temperate or cool temperate climate prevailed during the Eocene in the Mackenzie Delta area.

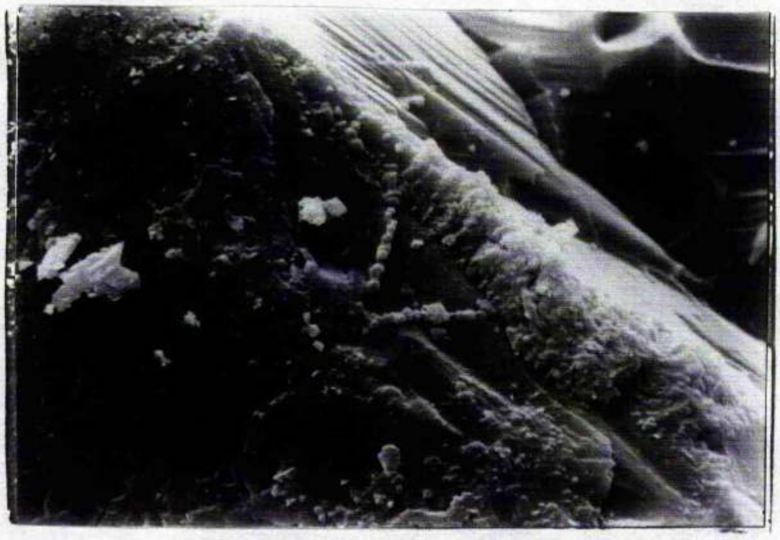


Plate XXII - SEM photomicrograph of NaCl or zeolite forming a string of crystals on a quartz grain. H-30, composit sample from interval 3200-3230 ft. 1000X.

CHAPTER VII

DIAGENETIC HISTORY

The term diagenesis used in this research refers to all the changes, physical and chemical, that are initiated in the sediments immediately after their deposition. Diagenesis could be accomplished by cementation, weathering, alteration, compaction, and solution of some minerals especially the less stable ones. The most important factors that control diagenesis are pressure, temperature, chemistry of pore water, composition of sediments, and time. Diagenesis can be classified into three major stages; eodiagenesis, mesodiagenesis, and telodiagenesis, using the Choquette and Pray (1970) terminology. Eodiagenesis includes all the changes that take place at or near the surface under normal pressure and temperature and before the initial pore water was squeezed out. Mesodiagenesis refers to the changes that take place during burial under higher temperature and pressure where ground solutions play an important role. Telodiagenesis is an advanced stage of diagenesis that takes place after uplift. Mesodiagenesis is the most important stage for the petroleum geologist because during this stage porosity reduction or its development takes place. Both eodiagenesis and mesodiagenesis are represented in the sediments of the Taglu Member.

Thin section study show that the most abundant cement in the Taglu sandstone is carbonate followed by silica then, to a lesser degree, authigenic clay minerals. Carbonate cement consists of several generations of dolomite both ferroan and non-ferroan, calcite, and siderite. The first generation of dolomite is non-ferroan found in contact with the grains in all cases. Where this dolomite is abundant number of grain to grain contact is very low and the sandstone is "cement supported" suggesting very early cementation before compaction. This generation of dolomite is followed in some cases by either ferroan or non-ferroan dolomite. When the three generations of dolomite are present in the same pore the second generation is always ferroan and the third is non-ferroan. The third type is more brownish than the first generation. Since dolomite is the product of replacement of calcite, it is not known whether the three generations precipitated as calcite one after the other then were dolomitized or each type was dolomitized individually after it was precipitated. The second case, however, is more plausible because each generation shows irregular or interrupted outlines which may be interpreted as the result of dissolution. Each type was precipitated, dissolved in whole or in part, then was dolomitized.

Dolomite, if present in small quantities, has erratic distribution. But where abundant it appears to be controlled by the environment of deposition. Dolomite is associated with the upper and lower part of the mouth bar deposit as in P-53, F-28, E-29, I-22, O-54, C-42, D-27, and H-30 boreholes (Appendix D). It is absent or nearly so in the middle part of the same deposit. Dolomite is also associated, in large or moderate quantities with the distributary channel and splay deposits as demonstrated in D-27, E-29, I-22, and O-14 boreholes (Appendix D).

Calcite, the second most abundant carbonate cement in the Taglu sandstone, is always non-ferroan. It is generally found growing over dolomite. Calcite, like dolomite, is found in moderate or large quantities in the lower and upper parts of the mouth bar deposit as can be seen in O-54, H-30, C-42, E-29 and I-22 boreholes and in the distributary channel deposit as in D-27, I-22 and O-14 boreholes (Appendix D). It is almost absent in the middle part of the mouth bar and pre-delta deposits, except in one case where it was found in abundance in a pro-delta deposit in O-54 borehole.

The high concentration of dolomite (originally calcite) and calcite in the lower and upper part of the mouth bar environments has been reported by Fisher et.al.(1969). Whelan III and Roberts (1973) also reported high concentration of calcite cement in freshwater swamps associated with deltas. Roberts and Whelan III (1975) found the same high concentration of calcite in coarse transgressive sediments over marsh deposits. Splay and distributary channel deposits are associated with swamp and marsh environments.

Calcite cement in the Taglu precipitated in the pores from carbonate - rich solutions. Marine water as well as calcareous shell fragments and detrital limestone in the sediments provided a rich source of calcium carbonate.

In general, calcite is formed by three different processes; directly from sea water, in the mixing zone of fresh water and marine water, and in fresh water when marine sediments trangress over swamps, interdistributary bays, marshes or any other reducing environment. One of the most important factors that controls the solubility of calcium carbonate is the pH. As pH increases calcite solubility decreases (Fig. 37) and when it reaches a certain level calcite precipitates from sea water. CO_2 enriched water has a low pH making it acidic. Upon the decay of organic matter in the sediments methane gas is generated which in turn is oxidized to produce CO_2 and eventually HCO_3 as indicated by these reactions:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$CO_2 + H_2O \rightarrow H_2\,CO_3$$

$$H_2\,CO_3 \rightarrow H^+ + HCO_3^-$$

When these carbonaceous rich sediments start to undergo compaction pore water is squeezed upward to the surface where pressure decreases. This decrease in pressure allows the CO_2 to escape resulting in an increase in pH, hence the precipitation of calcite. Also in the early stages of organic-matter-decay nitrogenous bases could be produced which also result in an increase in pH level (Garrison and Luternauer, 1971). Calcite could also precipitate from ground solutions supersaturated in Ca^{++} ions in the sediments after burial. Therefore, one would conclude that calcite could precipitate at or near surface conditions as well as long after burial. Fresh and marine waters are deficient in Fe^{++} ions, therefore, iron must have come from iron rich minerals in the sediments. As pressure and temperature increase coupled with a change in pH, iron could be leached from clay, biotite, or

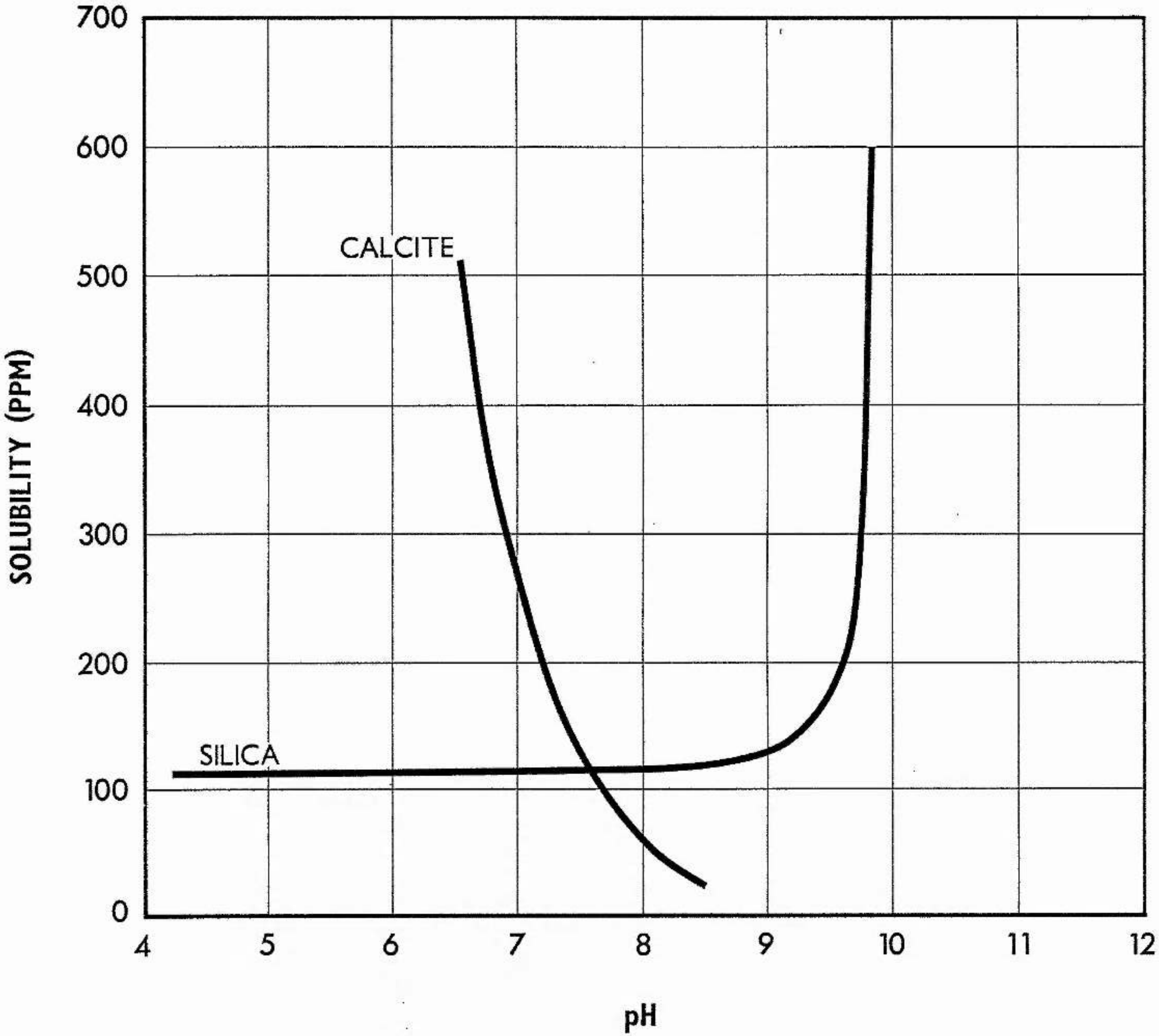


Figure 37 - Diagram showing relationship betweem solubility of silica and calcite and the pH.

other iron rich minerals. The leached iron/~~t~~ could precipitated with calcite to form ferroan calcite if chemical and physical conditions are favourable for such reaction. Upon dolomitization this calcite becomes ferroan dolomite.

Evamy (1969) stated that the presence of ferroan carbonate cement suggests diagenesis below the water table. Marine water is deficient in iron but ground solutions could be rich in it. Therefore, non-ferroan carbonate is expected to precipitate in the marine water environment or in an environment deficient in iron.

When the Taglu sand was deposited calcite or aragonite cement formed well before compaction and immediately after deposition. It is doubtful that this calcite was in great enough abundance to fill the entire pores simply because the $CaCO_3$ budget is limited in any deltaic environment and the initial pore space is very large. The calcite could have been deposited as a rim of small crystals around the grains. The size of these crystals was possibly controlled by the time of crystallization. The calcite must have been rich in Mg^{++} to promote its dolomitization. In most samples the latter dolomite is ferroan (Plate XXIV) and occasionally it is non-ferroan. After this stage of carbonate cementation dissolution took place to dissolve some or all of the second generation of dolomite which is mainly ferroan and some of the first generation non-ferroan dolomite which formed a rim around the grains. This conclusion is based on the observations that in many places the outer outline of the first generation of non-ferroan dolomite is irregular or that the rim is broken on the same grain and that another cement such as kaolinite is present where the dolomite is absent.

The small dolomite crystals of the first generation carbonate cement provided a substrate for the growth of the second generation of the ferroan calcite which was later dolomitized. A similar interpretation was introduced by Oldershaw (1971) in a study on Halkin and Wenlock limestone of Great Britain except in the latter case calcite was growing on calcite. Consequently non-ferroan calcite was deposited in the available pore space pro-

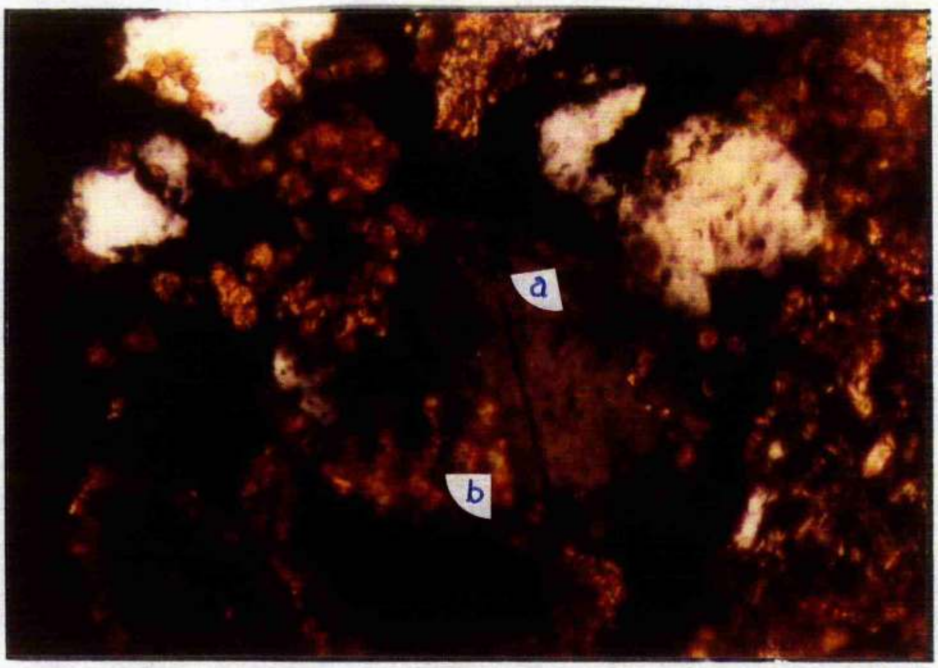


Plate XXIII - Thin section photographs showing siderite cement (a) which replaced dolomite. Notice some bright dolomite crystals (b) remained unreplaced within the siderite. D-27, 125X

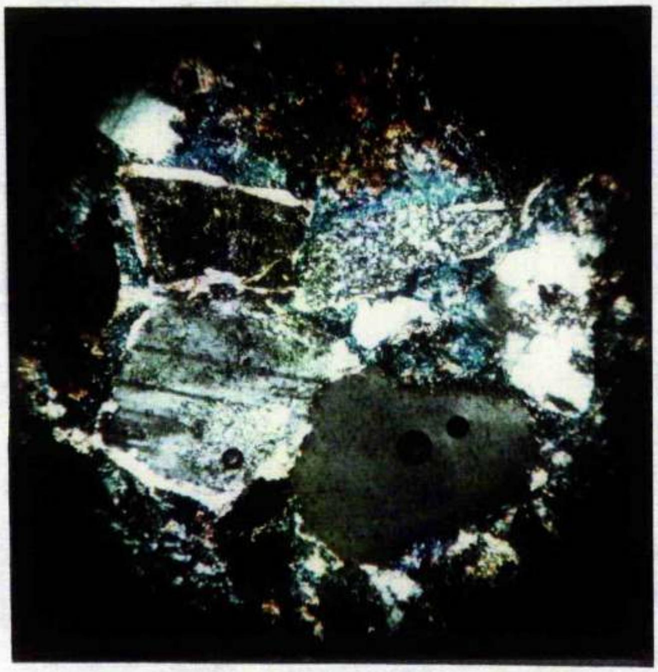


Plate XXIV - Thin section photograph showing ferroan dolomite (blue) growing over non ferroan dolomite (very light) which coats the grains. D-27, 150X vided by carbonate dissolution.

Siderite is the least common carbonate cement in the Taglu sandstone. It is found in the splay, distributary channel deposits and in a rare example in an upper mouth bar deposit (Appendix D). In a few thin sections siderite was observed forming directly on the grains suggesting an eodiagenetic stage. It is formed under reducing conditions in sediments rich in organics or with iron-rich minerals such as pyrite (Blatt et. al., 1972). It can also form in the mesodiagenetic or possibly in the telodiagenetic stages as a secondary mineral replacing calcite. Both primary and secondary siderite was observed in some of the examined thin sections. The first type is shown in Plate (X) and the second in Plate (XXIII). In the second type the replacement was not pervasive and some calcite or dolomite crystals remained unreplaced.

Silica cement in the Taglu sandstones was observed in abundance in samples collected from a depth in excess of 8000 ft. (2438 m) where gas is absent. In these samples the quartz grains show a concavo-convex contact relationship which is an advanced form of a pressure solution phenomenon. It is also present in some examples in association with distributary channels and pro-delta deposits as in C-42 and D-55 boreholes (Appendix D). Silica overgrowths on quartz grains are difficult to identify in thin sections, therefore, it might not be detected. Scanning electron microscope examination, however, revealed the presence of more silica than can be seen in thin sections. The type of silica observed was quartz. No opaline silica was seen anywhere in the research area.

Silica cement in the Taglu sandstones forms only on quartz grains. In samples viewed under the scanning electron microscope other cement such as kaolinite (Plate XIII), illite (Plate XV), chlorite, and calcite or dolomite were seen forming over the silica overgrowth. This may suggest that in certain examples silica is formed as a first cement.

Silica cement is formed in the three diagenetic stages. Since the telodiagenetic stage is not represented in the research area only the first two stages need be discussed. In the eodiagenetic stage silica cement is derived from many sources such as solution of siliceous shale, decomposition of feldspar (Fothergill, 1955), solution of silica secreting organisms (Siever, 1957) or from river water supersaturated with silica. Blatt et. al. (1972) stated that silica dissolves in river water in amounts ten times more than in marine water. Composition of river water is greatly controlled by the composition of the rock it flows over or infiltrates through. Silica can also precipitate directly from sea water (Mackenzie and Gees, 1971). Therefore, it is concluded from the above statements that eodiagenetic silica is expected, in a deltaic sandstone, to form near the outer limit of the sandstone in the distal mouth bar environment where shale is present in abundance (Fig. 38). Fuchtbauer (1974) reached a similar conclusion for the Buntsandstein and Dogger Beta sandstones. He stated that silica cementation frequently increases toward shale beds. Upon the compaction of shale silica rich solutions migrate into the sand to deposit their load of silica. In a distributary channel environment a zone of mixing occurs where river water rich in silica comes in contact with marine water. In this zone ionic exchanges take place and the pH level changes resulting in silica precipitation.

Silica cement could be derived from the decomposition of feldspar or from the replacement of quartz grains by dolomite. It could also be derived from pressure solution. The latter is usually the most important source of silica cement. Invoking Riecke's principle for quartz when two quartz grains are in contact with each other and a stress is applied silica is dissolved at the point of contact and is deposited at the lowest stress on the same grain. This dissolved silica could also be transported in some cases by ground solution to be deposited somewhere else. Therefore, the stress phenomenon could result in silica overgrowths and grain to grain pressure solution on the same grain. Clay, carbonaceous matter or hematite coatings promote pressure solution (Heald, 1956) as does a high pH. Other factors

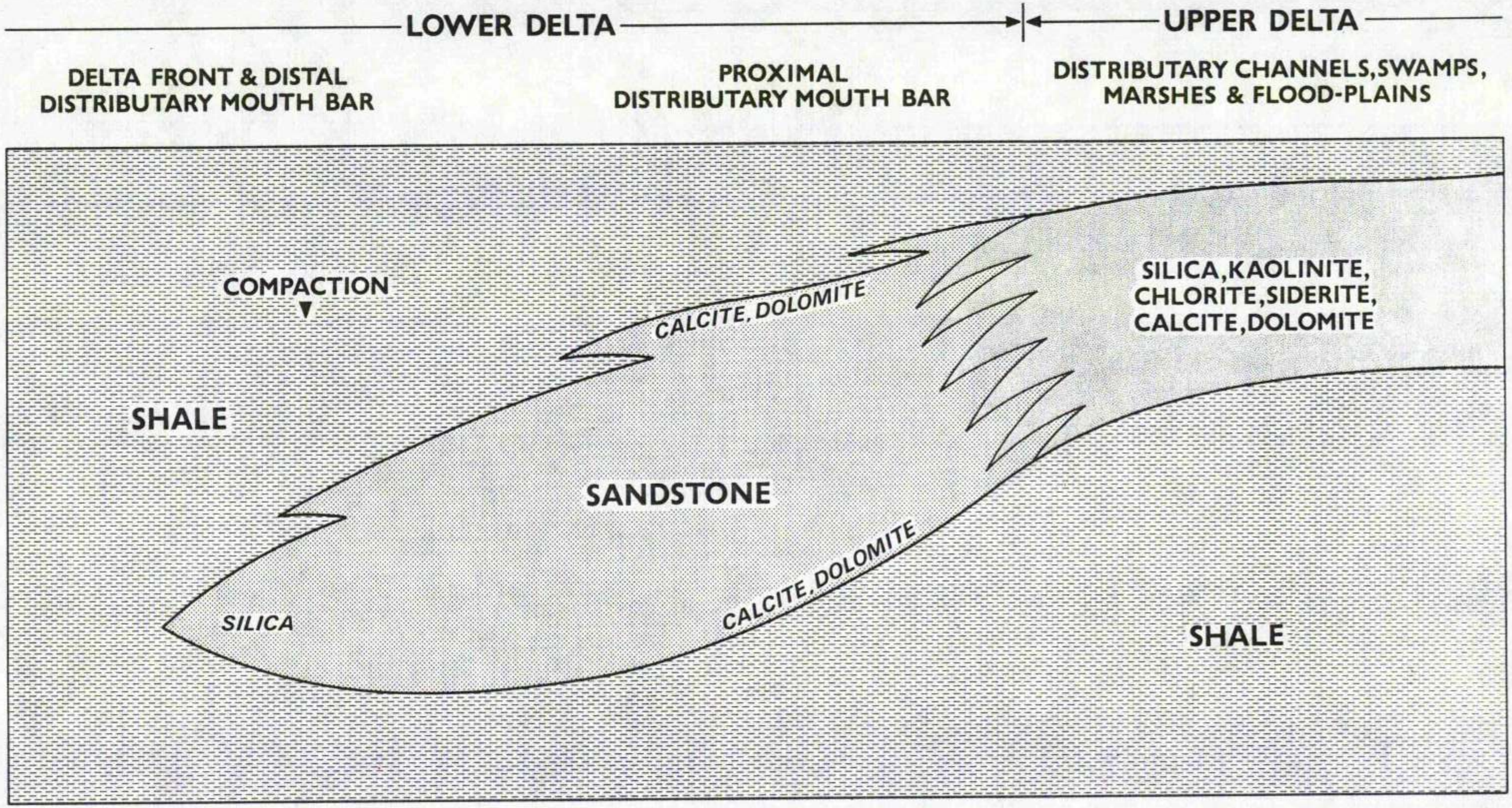


Figure 38 - Schematic cross-section showing distribution of early cement in a deltaic deposit. Modified from Fisher <u>et</u>. <u>al</u>. (1969).

are temperature, overburden or structural deformation, and time. Pittman (1972) stated that fine-grained sandstone is more susceptible to pressure solution than coarse-grained sandstone.

Authigenic clay minerals in the Taglu sandstone are present in minor quantities and no comprehensive conclusion can be drawn from their distribution. But because of their significance as environmental indicators their genesis will be discussed in some detail. The only authigenic clay minerals observed in thin sections or under the scanning electron microscope were kaolinite, illite and chlorite.

Kaolinite was observed in some samples from the upper delta deposit. It is a hydrous aluminum silicate that can be formed as a by-product of potash feldspar upon its weathering and the removal of potassium - a process known as kaolinitization of feldspar which starts shortly after deposition (Packham and Crook, 1960). Kaolinite is formed in acidic environments and is stable in fresh water and continental deposits (Folk, 1968). Its association with sediments indicates non-marine facies (Brown et. al., 1977; Folk, 1968). Füchtbauer (1974) stated that kaolinite cement is an early diagenetic (eodiagenetic) product in quartz sandstone. In the Taglu sandstone it is observed forming on top of small quartz overgrowths or filling an entire pore, being the only cement. This suggests that it could form in both eodiagenetic and mesodiagenetic stages. At depths in excess of 9845 ft. (3000 m) kaolinite breaks down and silica is released (Kisch, 1969) or may be transformed to dickite as suggested by Fuchtbauer (1974).

Authigenic chlorite is also mainly associated with the upper delta deposit. It is formed by direct precipitation from solution or as a product of alteration of mica. The iron rich variety of chlorite could be formed in the flood-plain environment (Liebling and Scherp, 1976) and in near-shore marine sediments (Folk, 1968). In the Taglu sandstone chlorite, when present forms a rim around the grains suggesting its formation in the eodiagenetic stage. Unlike kaolinite, it can survive deep burial. It is observed in a sample taken from a depth of 10409 ft. (3173 m) in Taglu D-55 borehole.

Illite seen in many samples and in different deposits is a hydrous mica. It can be formed in a potash rich environment such as that present in temperate and semiarid areas (Folk, 1968). It can also be the alteration product of other clay minerals as a result of marine diagenesis or through deep burial (Folk, 1968). Brown et. al. (1977) concluded that illite increases in the marine sediments. Therefore, it could be formed in the eodiagenetic and mesodiagenetic stages. In the Taglu sandstone it is found on top of chlorite and other cement indicating that it was formed as a mesodiagenetic product. Illite can be upgraded to sericite and muscovite at about 100^{o} C (Blatt et. al., 1972) suggesting that its crystal size becomes larger at depth. Therefore, some of the latter minerals in the Taglu sandstone could be illite in origin.

CHAPTER VIII

SUMMARY OF CONCLUSION

The tectonic elements of the Mackenzie Delta controlled the sedimentation during Eocene time when the Taglu Member was deposited. Because of its structural pattern the Recent Mackenzie Delta has remained in its place since Eocene.

The structure of the Mackenzie Delta in the research area is characterized by a series of folds and faults trending northwest - southeast and nearly perpendicular to the Donna River Fault zone. Most of these faults are normal except the Donna River Fault which is a strike slip.

The Taglu Member in its type section consists of two sedimentary cyclothems. Both show gradational change in lithology from predominantly shale on bottom to predominantly siltstone and finally sandstone on top. This change in lithology also coincides with an upward increase in grain size and a general increase in bed thickness. The Taglu Member forms a sandstone wedge which thins out and grades into shale in a northern direction.

The Taglu Member consists predominantly of quartz, chert, feldspar, rock fragments, micas, opaque minerals and cement. The cement consists of dolomite, calcite, siderite, silica, and to lesser amount of chlorite, illite, and kaolinite. Based on its composition the Taglu sandstone can be classified as quartz arenite and sublitharenite.

The Taglu Member represents a deltaic deposit which consists of two main deltaic cycles. These deltas are of the elongate type formed by fluvially dominated processes. Several environments maybe interpreted within the sequences. They include distributary channels, interdistributary bays and marshes, distributary mouth bars, and pro-delta. The sediments of these environments were deposited in a continuously but moderately sinking basin. The high influx of the sediments prograded the Taglu delta a considerable distance basinward.

One source area of the Taglu sediments was located somewhere to the south or southeast. Composition of the sandstone indicate at least two sediments sources. One was metamorphic and the other sedimentary. The Richardson Mountains and the Eskimo Lakes Arch supplied, at least in part, the Taglu sediments. A third source might have been well to the south. High gradient rivers transported a large part of the sediments in a cool temperate climate.

The most abundant cement in the Taglu sandstone is carbonate followed by silica then authigenic clay minerals. Carbonate cement consists of several generations of dolomite both ferroan and non-ferroan, calcite, and siderite. Silica is present in the form of silica overgrowth on quartz grains. Authigenic clay minerals in the Taglu sandstone are present in minor quantities and no comprehensive conclusion can be drawn from their distribution.

The environment of deposition controls to a large degree the type of cement. Each type could form as a first cement in certain environments. Therefore, no generalized sequence of cement in the Taglu sandstone can be established.

REFERENCES

Allen, J.R.L., Sediments of Modern Niger Delta; A summary and Review, in Deltaic Sedimentation, Modern and Ancient, J.P. Morgan, ed.: Soc. Econ. Paleon. Mineral., Sp. Pub. no. 15, p. 138-151.

Anderson, D.W. and Picard, M.D., 1971, Quartz extinction in Siltstone: Bull. Geol. Soc. Amer. v. 82, p. 181-186.

Austin, G. and Cumming, L., 1977, Stratigraphic Correlations, Biostratigraphic Zonation of Mackenzie Delta wells: Austion and Cumming Exploration Consultants, Calgary, Alberta.

Austin, G. and Cumming, L., 1976, Stratigraphic Correlation, Biostratigraphic Zonation of Cumming Exploration Consultants, Calgary, Alberta.

Barnes, C.R., Brideaux, W.W., Chamney, T.P., Clowser, D.R., Dunay, R.E., Fisher, M.J., Fritz, W.H., Hopkins, W.S., Jr., Jeletzky, J.A., McGregor, D.C., Norford, B.S., Norris, A.W., Pedder, A.E.H., Rauwerda, P.J., Sherrington, P.F., Silter, W.V., Tozer, E.T., Uyeno, T.T. and Waterhouse, J.B., 1974, Biostratigraphic Subsurface of the Northwest and Yukon Territories: Geol. Surv. Can., Paper 74-11.

Barrell, J., 1912, Criteria for the Recognition of Ancient Delta Deposits: Geol. Soc. Amer. Bull., v. 23, p. 377-446.

Bernard, H.A., Major, C.F., Jr., Parrott, B.S., and LeBlanc, R.J., Sr., 1970, Recent sediments of Southeast Texas: Bur. Econ. Geology, University of Texas, Austin, Report.

Blatt, H. Middleton, G., and Murray, R., 1972, Origin of Sedimenatry Rocks: Publish., Prentice-Hall, Inc., New Jersey, 634 p.

Bowerman, J.N., Coffman, R.C., 1975, The Geology of the Taglu Gas Field in the Beaufort Basin, N.W.T., in Canada's Continental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker, and D.J. Glass: Can. Soc. Petrol. Geol. Mem. 4, p. 649-662.

Brideaux, W.W., 1973, Cretaceous and Tertiary Assemblages (Palynomorphs): Geol. Surv. Can., Paper 72-38, p. 2-6.

Brown, L.F., Jr., 1969, Virgil and Lower Wolfcamp Repetitive Environments and the Depositional Model, North - Central Texas, in Symposium on Cyclic Sedimentation in the Permian Basin: West Texas Geol. Soc., P. 115-134.

Brown, L.F., Jr., Baily, S.W., Cline, L.M., and Lister, J.S., 1977, Clay Mineralogy in Relation to Deltaic Sedimentation Patterns of Desmoinesian Cyclothens in Iowa-Missouri: Clays and Clay Minerals, v. 25, p. 171-186, Pergamon Press, G.B.

Brown, L.F., Jr., and Fisher, W.L., 1976A, Seismic Facies Reflection Patterns: Examples from Brazilian Rift and Pull-Apart Basins: Bur. Econ. Geology, University of Texas, Austin, Report.

Brown, L.F., Jr., and Fisher, W.L., 1976B, Delta Seminar: Home Oil Co. Ltd. Delta Manual, 244 p.

Bruce, C.H., 1973, Pressured Shale and Related Sediment Deformation: Mechanism for Development of Regional Contemporaneous Faults: Bull. Amer. Assoc. Petrol. Geol., v. 57, p. 878-886.

Bruce, C.J., and Parker, E.R., 1975, Structural Features and Hydrocarbon Deposits in the Mackenzie Delta: Proc. Ninth World Petroleum Congress, Tokyo, v. 2, Applied Science Publish Ltd., London, p. 251-261.

Carrigy, M.A., and Mellon, G.B., 1964, Authigenic Clay Minerals Cements in Cretaceous and Tertiary Sandstones of Alberta: Jour. Sed. Pet., v. 34, p. 461-472.

Chamney, T.P., 1973, Tuktoyaktuk Peninsula Tertiary and Mesozoic Biostratigraphy Correlation, in Report of Activities, Part A: April to October, 1972: Geol. Surv. Can., Paper 73-1, Pt. A, p. 253.

Chamney, T.P., 1972, Biostratigraphic contributions from the Arctic Coastal Plain West of the Mackenzie Delta: Geol. Surv. Can., Paper 72-1A, p. 202-203.

Chamney, T.P., 1969, Tertiary and Cretaceous Biostratigraphic Divisions in the Reindeer D-27 Borehole, Mackenzie River Delta: Geol. Surv. Can., Paper 70-30, p. 69-72.

Chouquette, P.W., and Pray, L.C., 1970, Geologic Nomenclature and Classification of Porosity in Sedimentary Carbonates: Amer. Assoc. Petrol. Geol. Bull., v. 54, p. 207-250.

Coleman, J.M., and Gagliano, S.M., 1964, Cyclic Sedimentation in the Mississippi River Delta Plain: Trans. Gulf Coast Assoc., Geol. Soc. Trans., v. 14, p. 67-80.

Cote, R.P., Lerand, M.M., and Rector, R.J., 1975, Geology of the Lower Cretaceous Parsons Lake Gas Field, Mackenzie Delta, Northwest Territories, in Canada's Continental Margins and Offshore Petroleum Potential, C.J., Yorath, E.R., Parker and D.J. Glass, eds.: Can. Soc. Petrol. Geol., Mem. 4, p. 613-632.

Dailly, G.C., 1976, A possible Mechanism Relating Progradation, Growth Faulting, Clay Diapirism and Overthrusting in a Regressive Sequence of Sediments: Bull. Can. Petrol. Geol., v. 24, p. 92-116.

Dennen, W.H., 1967, Trace Elements in Quartz as indicators of Provenance: Geol. Soc. Amer. Bull., v. 78, p. 125-130.

Evamy, B.D., 1969, The Precipitational Environment and Correlation of some Calcite Cements Deduced from Artificial Staining: Jour. Sed. Pet., v. 39, p. 787-793.

Fisher, W.L., 1969, Facies Characterization of Gulf Coast Basin Delta Systems, with Holocene Analogues; Trans. Gulf Coast Assoc. Geol. Socs., v. 19, p. 239-261.

Fisher, W.L., 1968, Basic Delta Systems in the Eocene of the Gulf Coast Basin (abs.) Trans. Gulf Coast Assoc. Geol. Socs., v. 18, p. 48.

Fisher, W.L., and Brown, L.F., Jr., 1972, Clastic Depositional Systems - a Genetic Approach to Facies Analysis: Bur. Econ. Geology, University of Texas, Austin, p. 211.

Fisher, W.L., Brown, L.F., Jr., Scott, A.J., and McGowan, J.H., 1969, Delta Systems in the Exploration for Oil and Gas: a research colloquim, Bur. Econ. Geology, University of Texas, Austin.

Fisk, H.N., 1955, Sand Facies of Recent Mississippi Delta Deposits: Proc. 4th World Petroleum Congress, Rome, sec. 1, p. 377-398.

Folk, R.L., 1968, Petrology Sedimentary Rocks: Hemphill's Bookstore, Austin Texas, p. 107.

Folk, R.L., 1964, Petrology of Sedimentary Rocks: Hemphill's Bookstore, Austin, Texas.

Fothergill, C.A., 1955, The Cementation of Oil Reservoir Sands and its Origin: Proc. 4th World Petroleum Congress, Sect. I, p. 300-312.

Frazier, D.E., 1967, Recent Deltaic Deposits of the Mississippi River; their Development and Chronology: Trans. Gulf Coast Assoc. Geol. Socs., v. 17, p. 287-315.

Fuchtbauer, H., 1974, Sediments and Sedimentary Rocks 1: Publish, Halstead Press, John Wiley and Sons, Inc., New York, 464 p.

Fuchtbauer, H., 1961, Zur Quarzneubildung in Erdollager statten: Erdol. u. Kohle, v. 14, p. 169-173.

Glaister, R.P., and Hopkins, J., 1974, Turbidity - Current Debris-flow Deposits <u>in Use</u> of sedimentary Structures for Recognition of Clastic Environments, <u>M.S. Sh</u>awa, ed.: Can. Soc. Petrol. Geolog., Unnumbered publication, 66 p.

Garrison, R.E., and Luternauer, J.L., 1971, Textures of Calcitic Cements formed During Early Diagenesis Fraser Delta, British Colombia, <u>in</u> Carbonate Cements, O.P. Bricker, ed: John Hopkins University Studies in Geology, no. 19, p. 151-154.

Goldstein, A., Jr., 1948, Cementation of Dakota Sandstones of the Colorado Front Range: Jour. Sed. Pet., v. 18, p. 108-125.

Gould, H.R., 1970, The Mississippi Delta Complex, <u>in</u> Deltaic Sedimentation Modern and Ancient J.P. Morgan, ed.: Soc. Econ. Paleon. Mineral, Sp. Pub. no. 15, p. 3-30.

Heald, M.T., 1956, Cementation of Simpson and St. Peter Sandstones in parts of Oklahoma, Arkansas, and Missouri: Jour. Geol., v. 64, p. 16-30.

Holmes, D.W., and Oliver, T.A., 1973, Source and Depositional Environments of the Moose Channel Formation, Northwest Territories; Bull. Can. Petrol. Geol., v. 21, p. 435-478.

Keller, W.D., 1970, Environmental Aspects of Clay Minerals: Jour Sed. Pet., v. 40, p. 788-813.

Kisch, H.J., 1969, Coal-Rank and Burial Metamorphic Mineral facies: Advances in Organic Chemistry, p. 407-425; Pergamon Press, G.B.

LeBlanc, R.J., Sr., 1977, Distribution and Continuity of Sandstone Reservoirs. Part 1: Jour. Petrol. Tech., p. 776-804.

Lerand, M., 1975, Beaufort Sea in The Future Petroleum Provinces of Canada, R.G. McCrossan, ed.: Can. Soc. Petrol. Geol., Mem. 1, p. 315-386.

Lerbekmo, J.F., 1961, Porosity Reduction in Cretaceous Sandstones of Alberta: Alberta Soc. Petrol. Geol. Jour., v. 9, p. 192-199.

Liebling, R.S., and Scherp, H.S., 1976, Chlorite and Mica and Indicators of Depositional Environment and Provenance: Geol. Soc. Amer. Bull.. v. 87, p. 513-514.

Mackenzie, F.T., and Gees, R., 1971, Quartz: Synthesis at Earth-Surface Conditions: Science, v. 173, p. 533-535.

Martin, L.J., 1961, Tectonic Framework of Northern Canada, in Proc. first International Symposium on Arctic Geology, G.O. Raasch ed: Univ. Toronto Press, v. 1, p. 442-457.

Miall, A.D., 1976, Facies Model 4; Deltas: Geoscience Canda, v. 3, p. 215-227.

Millot, G. 1970, Geology of Clays: Publish Springer - Verlag, New York, p. 429.

Morgan, J.P., Coleman, J.M., and Gagliano, S.M., 1968, Mudlumps: Diapiric Structures in Mississippi Delta Sediments: Amer. Assoc. Petrol. Geol., Mem. 8, p. 145-161.

Mountjoy, E.W., 1967, Upper Cretaceous and Tertiary Stratigraphy, Northern Yukon Territory and Northwestern District of Mackenzie: Geol. Surv. Can., Paper 66-16.

Norris, D.K., 1972, Structural and Stratigraphic Studies in the Tectonic Complex of Northern Yukon Territory, North of Porcupine River: Geol. Surv. Can., Paper 72-1, pt. B., p. 91-99.

Oldershaw, A.E., 1971, The Significance of ferroan and Non-Ferroan Calcite Cements in the Halkin and Wenlock Limestone (Great Britain), in Carbonate Cements, O.P. Bricker, ed.: John Hopkins University Studies in Geology, no. 19, p. 225-229.

O'Neil, J.J., 1924, Report on the Canadain Arctic Expedition, 1913-1918, v. 11, Geology and Geography; Part A; The Geology of the Arctic Coast of Canada, West of the Kent Peninsula: Government Printer, Ottawa, p. 1A-107A.

O'Neil, J.J., 1915, Canadian Arctic Expedition; Geol. Surv. Can., Summer Report 1914, p. 112-115.

Packham, G.H., and Crook, K.A., 1960, The Principle of Diagenetic Facies and some of its Implications: Jour. Geol., v. 68, p. 392-407.

Patton, W.W., Jr., and Hoar, J.M., 1968, The Kaltag Fault, West-Central Alaska: U.S. Geol. Surv. Prof. Paper 6000-D, p. D147-D153.

Philipp. W., Drong, H., Fuchtbauer, H., Hddenhorst, H., and Jankowsky, W., 1963, The History of Migration in the Gifhorn Trough, NW Germany: 6th World Petrol. Congress, Sec. 1, Pap. 19, p. 457-481.

Pittman, E.D., 1972, Diagenesis of Quartz in Sandstones as Revealed by Scanning Electron Microscopy: Jour. Sed. Pet., v. 42, p. 507-519.

Pye, W.D., 1944, Petrology of Bethel Sandstone of South Central Illinois: Amer. Assoc. Petrol. Geol. Bull., v. 28, p. 63-122.

Roberts, H.H., and Whelan, T., III, 1975, Methane derived Carbonate Cements in Barrier and Beach Sands of a subtropical Delta Complex: Geochem. Cosmoch Acta, v. 39, p. 1085-1089.

Russel, W.L., 1960, Principles of Petroleum Geology: Pub. McGraw-Hill Book Co., Inc., p. 503.

Schmidt, V., and McDonald, D., (In press), The Role of Secondary porosity in the Course of Sandstone Diagenesis: Soc. Econ. Paleon. Mineral., Sp. Pub. no. 26.

Scruton, P.C., 1960, Delta Building and the Deltaic Sequence, in F.P. Shepard and other, ed.: Recent Sediments Northwest Gulf of Mexico, Amer. Assoc. Petrol. Geol., p. 82-102.

Selley, R.C., 1975, Subsurface Diagnosis of Deltaic Deposits with Reference to the Northern North Sea: Norwegian Petroleum Society, Jurassic Northern North Sea Symposium, Stavanger Sep. 28-30.

Shawa, M.S., Lee, P.J., Young, F.G., 1974, Deltas: A General Review in use of Sedimentary Structures for Recognition of Clastic Environments, M.S. Shawa, ed.: Can. Soc. Petrol. Geolog. unnumbered publication, p. 66.

Siever, R., 1957, The Silica Budget in the Sedimentary Cycle: Amer. Mineral, v. 42, p. 821-841.

Smithson, F., and Brown, G., 1954, The Petrography of Dickitic Sandstones in North Wales and Northern England: Geol. Mag., v. 91, p. 177-188.

Staplin, F.L., 1976, Tertiary Biostratigraphy Mackenzie Delta Region, Canada: Mackenzie Delta Region, Canada: Bull. Can. Petrol. Geol., v. 24, p. 117-136.

Tailleur, I.L., and Brosge, W.P., 1970, Tectonic History of Northern Alaska, in Proc. Geological Seminar North Slope Alaska: Amer. Assoc. Petrol. Geolog. Palo Alto, Calif., Feb. 1-3.

Visher, G.S., 1969, Grain-size distributions and depositional processes: Jour. Sed. Pet., v. 39, p. 1074-1106.

Waldschmidt, W.A., 1941, Cementing materials in sandstones and their probable influence on migration and accumulation of Oil and Gas: Amer. Assoc. Petrol. Geolog. Bull., v. 25, p. 1839-1879.

Walker, T.R., 1967, Formation of Red Beds in Ancient and Modern Deserts: Geol. Soc. Amer. Bull., v. 78, p. 353-368.

Weimer, R.J., 1961, Uppermost Cretaceous Rocks in Central and Southern Wyoming and Northwestern Colorado, in Symposium on Late Cretaceous Rocks, Wyoming and Adjacent Areas: Wyoming Geol. Assoc. 16th Ann. Field Conference, Casper, Wyoming, Petroleum Info., p. 17-28.

Whelan, T., III, and Roberts, H.H., 1973 Carbon Isotope Composition of Diagenetic Carbonate Nodules from Freshwater Swamp Sediments: Jour. Sed. Pet., v. 43, p. 54-58.

Wilson, M.D., and Pittman, E.D., 1977, Authigenic Clays in Sandstones: Recognition and Influence on Reservoir Properties and Paleoenvironmental Analysis: Jour. Sed. Pet., v. 47, p. 3-31.

Wright, L.D., and Coleman, J.M., 1973, Variations in Morphology of Major River Deltas as functions of Ocean Wave and River Discharge Regimes: Bull. Amer. Assoc. Petrol. Geol., v. 57, p. 370-417.

Young, F.G., 1975, Upper Cretaceous Stratigraphy, Yukon Coastal Plain and Northwestern Mackenzie Delta: Geol. Surv. Can., Bull. 249, p. 83.

Young, F.G., 1972, Cretaceous Stratigraphy between Blow and Fish Rivers, Yukon Territory: in Report of Activities, Surv. Can., Paper 72-1, Pt. A, p. 229-235.

Young, F.G., Myhr, D.W., and Yorath, C.J., 1976, Geology of the Beaufort - Mackenzie Basin: Geol. Surv. Can., Paper 76-11, p. 63.

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE P-53

METHOD: AA

METHOD: XRF

Depth (ft.)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
5100	99	83	208	474	207	0.68	91	20	396
5200	108	92	201	359	199	0.54	97	17	377
5300	108	92	208	407	185	0.66	92	16	384
5400	96	92	193	416	192	0.63	101	22	410
5500	93	83	201	377	187	0.64	88	16	378
5600	105	83	179	440	190	0.68	101	20	306
5700	116	75	216	343	257	0.68	103	18	123
5800	88	83	141	597	171	0.59	85	19	280
5900	65	55	104	865	143	0.50	62	11	241
6000	82	75	126	713	496	0.54	82	12	264
6100	52	44	100	415	116	0.46	57	6	287
6200	58	44	100	590	165	0.66	93	14	237
6300	83	58	100	598	108	0.64	93	16	294
6400	61	58	116	547	168	0.72	76	12	245
6500	70	66	124	832	140	0.72	58	11	262
6600	70	66	132	754	167	0.72	64	12	234
6700	64	66	116	537	122	0.71	71	13	280
6800	86	66	132	468	164	0.76	88	16	391
6900	52	73	140	405	186	0.81	99	22	407
7000	77	58	85	461	149	0.29	87	12	371
7100	64	37	100	385	184	0.64	57	11	260
7200	67	51	100	883	199	0.63	70	15	234
7300	70	44	100	869	110	0.66	81	16	263
7400	80	66	108	622	142	0.39	56	16	297
7500	67	44	75	65	114	0.30	78	15	263

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE I-22

METHOD: AA

METHOD: XRF

Depth (ft)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
4600	62	52	96	385	106	0.58	84	17	234
4700	53	39	96	428	104	0.26	79	16	227
4800	73	59	126	530	148	0.72	95	17	211
4900	94	59	126	571	156	0.73	98	20	227
5000	75	51	107	425	126	0.62	87	16	248
5100	79	46	107	422	154	0.59	97	17	217
5200	66	46	98	438	108	0.56	84	15	211
5300	75	46	103	414	114	0.60	93	20	234
5400	101	51	117	472	131	0.69	111	20	232
5500	95	41	107	299	125	0.69	100	18	263
5600	107	55	121	418	129	0.74	112	20	238
5700	112	60	117	418	155	0.69	93	17	227
5800	125	60	117	379	133	0.71	98	17	216
5900	86	41	98	300	111	0.56	75	12	183
6000	73	41	98	256	151	0.53	62	11	196
6100	66	41	98	345	111	0.57	67	13	201

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE H-30

METHOD: AA

METHOD: XRF

Depth (ft)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
2800	93	75	140	769	133	0.87	96	21	268
2900	82	68	132	606	116	0.29	94	17	252
3000	82	75	132	578	118	0.81	92	17	257
3100	100	83	140	666	151	0.57	97	16	222
3200	82	75	132	926	114	0.42	85	25	229
3300	75	57	131	1643	96	0.69	70	17	179
3400	91	64	146	396	128	0.85	84	18	268
3500	91	57	139	611	131	0.81	74	16	231
3600	64	57	131	622	111	0.64	60	16	237
3700	47	36	100	170	96	0.08	35	5	151
3800	59	36	139	388	118	0.56	55	12	192
3900	47	36	109	607	111	0.37	57	2	146
4000	59	43	131	527	159	0.60	63	9	199
4100	64	43	131	565	120	0.59	55	12	196
4200	59	57	102	326	111	0.30	49	8	170
4300	85	57	117	527	126	0.72	91	20	251
4400	85	57	104	517	124	0.75	113	4	241
4500	72	50	124	475	109	0.70	71	0	237
4600	80	57	117	552	120	0.70	81	17	254
4700	69	43	109	419	100	0.52	73	11	228
4800	86	57	125	471	125	0.75	79	14	255
4900	100	64	142	541	138	0.78	50	18	248
5000	89	64	150	775	144	0.81	77	17	261
5100	95	64	142	579	150	0.78	87	20	260
5200	95	64	133	582	142	0.75	36	17	267

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE O-14

METHOD: AA

METHOD: XRF

Depth (ft)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
2500	44	55	84	5010	105	0.38	41	10	153
2600	55	46	164	2720	168	0.51	53	14	192
2700	46	37	84	2720	90	0.37	41	10	122
2800	44	32	79	4430	81	0.37	41	10	126
2900	55	37	93	3500	102	0.39	39	11	129
3000	57	41	74	3030	84	0.41	38	13	134
3100	48	51	98	2410	68	0.40	42	12	165
3200	55	28	93	2560	64	0.39	36	11	181
3300	66	86	94	2540	115	0.47	55	12	210
3400	59	34	37	2590	113	0.05	48	15	195
3500	49	34	80	1770	247	0.31	39	12	140
3600	45	43	75	1470	388	0.30	40	10	159
3700	66	163	84	1380	554	0.40	66	14	211
3800	49	68	80	1720	400	0.26	35	15	168
3900	59	30	65	2240	90	0.34	53	17	185

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE G-33

METHOD: A-A | METHOD: XRF

Depth (ft.)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
7100	99	79	75	587	153	0.52	99	15	238
7200	127	79	126	235	139	0.66	129	19	244
7300	120	87	111	1469	161	0.59	128	18	249
7400	120	63	119	208	163	0.62	124	18	232
7500	103	50	89	187	90	0.53	103	21	249
7700	106	79	111	267	148	0.50	94	15	251
7800	93	55	111	416	165	0.44	91	14	261
7900	72	55	89	507	160	0.44	108	12	197
8000	106	71	126	523	151	0.54	130	21	200
8100	117	79	134	545	337	0.57	107	19	221
8200	58	63	149	272	92	0.44	111	11	215
8300	69	71	119	144	97	0.50	67	10	303
8400	75	63	134	240	112	0.56	76	14	253
8500	75	55	126	254	105	0.52	80	10	212
8600	75	79	111	459	138	0.57	83	16	252
8700	96	79	149	625	573	0.64	93	22	275
8800	110	79	149	590	346	0.68	102	19	251
8900	96	79	141	504	161	0.64	89	19	239
9000	106	79	141	350	182	0.69	100	24	282
9100	91	100	126	461	157	0.68	98	17	246
9200	85	92	104	506	163	0.43	109	24	277
9300	65	67	97	477	94	0.39	66	11	280
9400	88	92	119	519	149	0.61	85	5	263
9500	79	92	89	459	234	0.08	88	17	238

APPENDIX A ANALYTICAL DATA SHEET BOREHOLE E-29

METHOD: AA | METHOD: XRF

Depth (ft)	Li ppm	Ni ppm	Cr ppm	Mn ppm	Zn ppm	Ti02%	Rb ppm	Y ppm	Zr ppm
4600	71	48	100	1283	117	0.70	87	15	234
4700	100	66	132	919	143	0.48	109	20	265
4800	42	36	68	600	74	0.57	63	13	206
4900	50	30	75	915	85	0.58	85	7	189
5000	50	30	23	1610	80	0.35	47	13	183
5100	71	36	83	1400	119	0.62	56	12	223
5200	54	30	75	1774	87	0.57	43	11	226
5300	39	30	60	1338	71	0.43	40	11	189
5400	46	66	60	919	126	0.49	45	9	136
5500	29	30	38	660	48	0.28	35	4	76
5600	50	42	60	1690	84	0.48	42	10	183
5700	57	42	68	795	85	0.56	94	11	208
5800	46	36	60	1500	79	0.49	35	8	166
5900	61	42	60	801	93	0.55	63	11	226
6000	86	54	90	581	138	0.69	89	16	232
6100	79	60	93	686	118	0.65	95	12	228
6200	42	27	92	733	64	0.33	43	8	142
6300	65	50	75	1245	87	0.56	71	12	187
6400	45	40	60	1881	85	0.29	42	9	151
6500	74	40	52	748	110	0.61	56	14	261
6600	68	68	83	1151	91	0.55	78	16	227
6700	68	40	75	640	89	0.53	68	11	222
6800	54	33	68	640	70	0.41	51	9	173
6900	79	50	83	815	149	0.62	83	16	260
7000	91	63	100	642	151	0.70	93	13	262

APPENDIX B

A summary of compositional analysis of point counted thin sections from the Taglu sandstones. Results are computed in percentages.

Borehole	Sample Depth	Quartz	Chert	Plagio.	K-spar	R.F.	Micas	Dol. Cement	Carb. Frags.	Matrix	Calc. Cement	Siderite Cement	Silica Overgrowth	Anhyd.	Kaolinite	Chlorite	Illite
G-33	8154	37	32	2	4	9	2	4		2		2	1		1	<1	1
	8399	27	25	6		10	6		2	6		2			6	2	6
	8453	29	34	<1	7	14	<1	2	<1	6		1	3		3		4
	8511	31	38	6	<1	7	2			3		4	4		2	1	3
	8227	45	28	5	2	6	1	6	<1	3		3	<1		1		2
	8170	37	24	1		16	1	4	2	4	1	1	2				
	8205	36	30	3	2	10	3	1	1	9		<1	4		<1		
	8264	24	52		1	16		2		2			<1		<1		1
J-23	3100-3200	28	29	1	<1	5	2	18	1	2	6	3					1
O-54	3040-3050	34	20	4	3	7	3	4	3		17	3				1	2
	3400-3410	33	30	2	<1	12	2	<1		6		13					
	3640-3650	32	20	3	1	10	4	7	2		19					1	1
D-55	10413	56	21	2	3	6	2	2	2				7				
	10437	34	40	4	1	4	6	2	2	1			4				1
	10515	31	26	1	2	12	1	9	2	2		4	4		5		
	10700-10800	36	30	7	1	4	3	4	1	7	1		3				
	10800-10850	46	21	5	2	7	4	4	3	5		3	2				
	10850-10900	46	26	3		2	5	4	2	5		2	4				
	11200-11300	39	27	4	2	2	2	2	5	9	1		4				1
D-27	10600-10700	36	33	2	3	9	5	4	4	1		1	6				
	3600-3700	34	37	5	<1	6	2	8	1	1	1				2	1	3
	3700-3800	37	17	1	3	3	2	21	1	1	12	2					
	3800-3850	30	19	4	3	8	1	26			9	1					
	3850-3900	30	28	2	4	6	6	18	3	1	5						

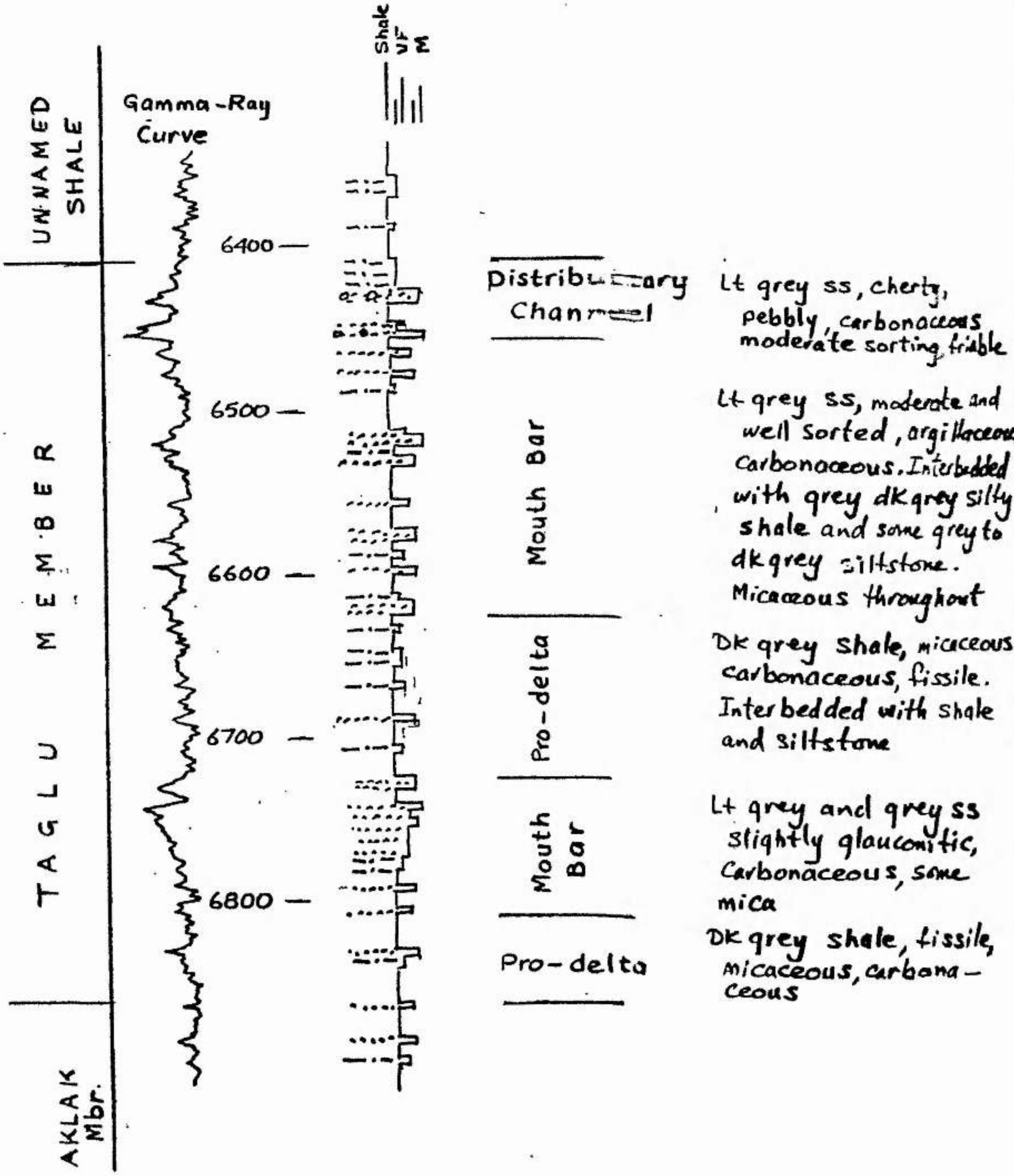
Borehole	Sample Depth	Quartz	Chert	Plagio.	K-spar	R.F.	Micas	Dol. Cement	Carb. Frags.	Matrix	Calc. Cement	Siderite Cement	Silica Overgrowth	Anhyd.	Kaolinite	Chlorite	Illite
D-27	3900-4000	44	15	3	3	3	3	20	2	<1	1	4				<1	
	4000-4100	37	24	3	1	6	1	9	2	4	10	2					
	4100-4200	23	31	2	5	8	2	5			15	7					
C-42	9418	31	39	4	2	8	3	5	1	2		<1	2				1
	9400-9450	45	14	3	<1	7	4	10	4	4	3	<1	2				
	9450-9500	37	27	2		5	6	7	2	3	7	4	1				
	9536	32	36	1	3	5	3	3	1	14		1				1	
	9650-9700	52	19	3	1	5	4	5	4	3		2	2			1	
	9691	34	32	3	1	7	3	5	2	2		6	2		1	1	
	9699	30	35	3	2	11	3	3	1	1		4	4			<1	
	9758	31	29	5	2	7	7	7	2	5			3		<1	1	1
	9900-10000	31	20	3	3	10	6	2	2	11	1	9	2				1
P-53	5000-5100	44	18	2	1	3	6	5	4	11		2				1	
	5100-5200	43	11	2	1	3	2	23	6	4	4	2					
	5200-5300	51	11	1	1	5	3	15	3	3	2	1	1				
	5300-5400	39	24	4	3	2	9	5	5	5		5					2
	5400-5500	44	14	1	1	1	4	3	1	26		2					
	5900-6000	30	25	3	3	5	3	14	4	8		5					
F-28	3600-3700	33	16	2	3	4	3	16	4	11	2	2					4
	3700-3800	46	26	6	1	5	3	3	1	3		1					5
	3900-4000	37	20	4	4	4	6	4	3	19							1
	4000-4100	28	30	5	3	6	5	5	1	14		1					2
E-29	4330	35	23	3	3	7	2	7	1	1	17	2					<1
	4020-4030	30	28	4	1	7	3	4	3	1	19						1
	4230-4230	28	31		4	7	4	8	1	1	7	6			1	<1	2
	3920-3940	28	47		2	11		1	5		2	4					

Borehole	Sample Depth	Quartz	Chert	Plagio.	K-spar	R.F.	Micas	Dol. Cement	Carb. Frags.	Matrix	Calc. Cement	Siderite Cement	Silica Overgrowth	Anhyd.	Kaolinite	Chlorite	Illite
I-22	1570	36	20	1	1	7	3	9	3	1	19	1					1
	1420	26	64		3	6		2									
	1450	32	17	4	3	7	1	7	2	1	25	1					<1
O-14	1470-1480	25	23	1	3	7	6	8	2	1	20	1				2	2
	1700-1800	33	38	1	1	6	5	12			1	1			1		1
	1802	40	37	2	2	5	3	2	2	4			1				1
	1800-1850	32	34	1	1	8	3	4	<1	3		1					1
	1900-2000	29	31	3	2	5	7	1	5	9		6					3
H-30	3200-3230	19	25	3	5	8	2	9	2	1	25						
	3290-3330	14	34	3	7	3	3				32						
	2980-3000	25	61		3	4		2	1			3					
	3370-3390	36	40		1	13		3	3		1		1				
	3500-3600	33	20	2	<1	9	<1	13	1	13		8					1
	3450-3500	29	18	2	1	7	2	15	1	18		6					2
	3600-3640	27	31	<1	7	2	<1	9	2	21		<1	1				<1
	3700-3800	28	23	7	3	7	2	12	1	11		3					1
	3800-3850	27	37	2	2	3	1	9	1	5		9					<1
	3850-3900	28	38	3	1	3	<1	5		18		2					1
P-03	8485	38	50		1	7	1		2	2		1	1		2		
	8530	40	15	2	<1	8	9		3		10	5	1		1	<1	1
	8660	32	37	3	4	13	4		2	2			4		<1		
	8730	38	18	4	1	11	5		3	6	1	10	1		1		
	8816	38	26	1	3	20	3		1		1	2			3	2	1
	9190	47	22	3	2	7	2		2	2	4	4	3			1	
	9325	35	25	<1	1	5	1	1		16	6	3	3		1		
	9590	51	16	2	2	8	5		1	8		2	5				
	9952	36	14	7	<1	20	23			8	1	6	2			2	

APPENDIX C

STRATIGRAPHIC SECTION A-28

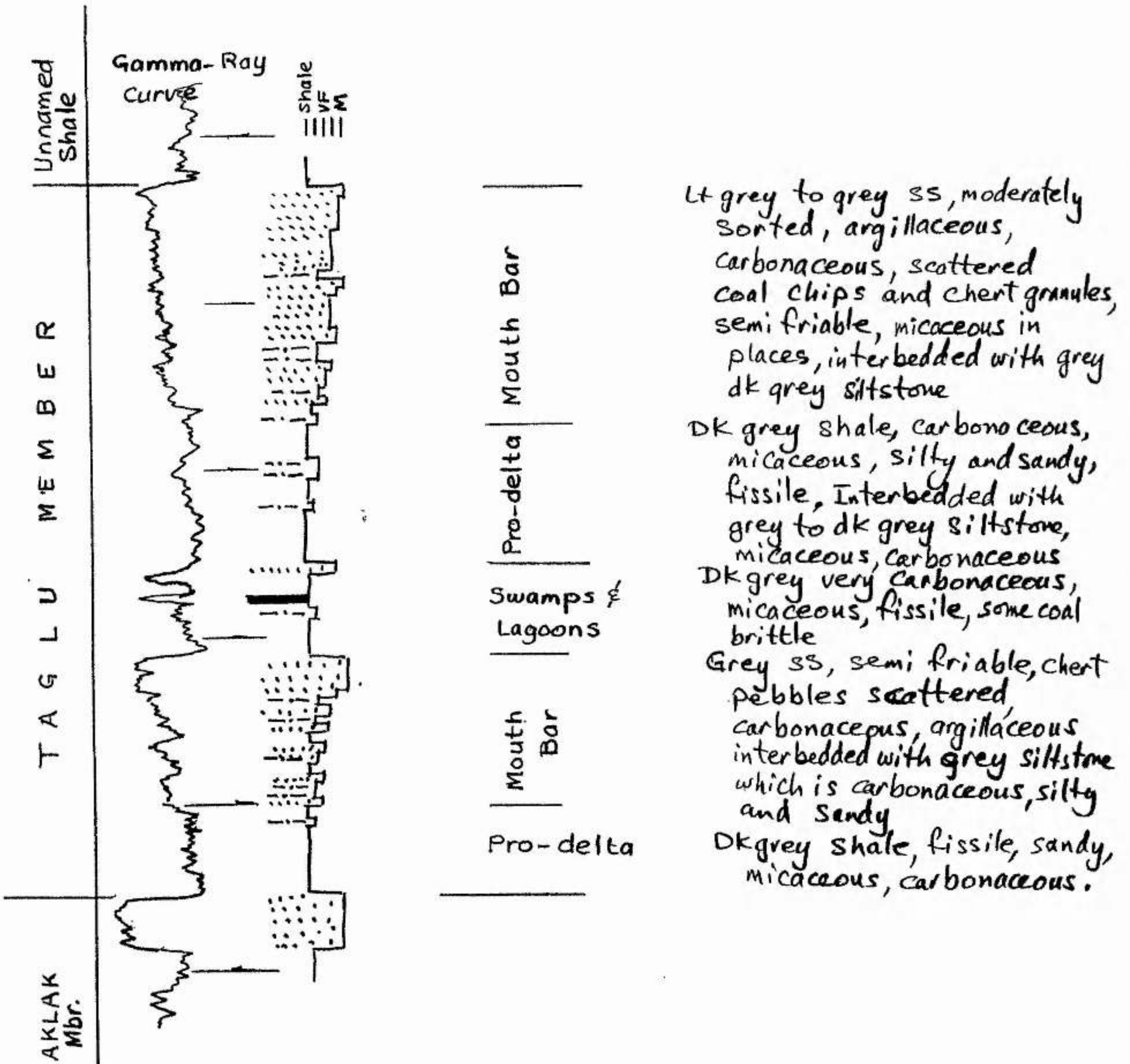
(for symbols see figure 20)



APPENDIX C

STRATIGRAPHIC SECTION J-23

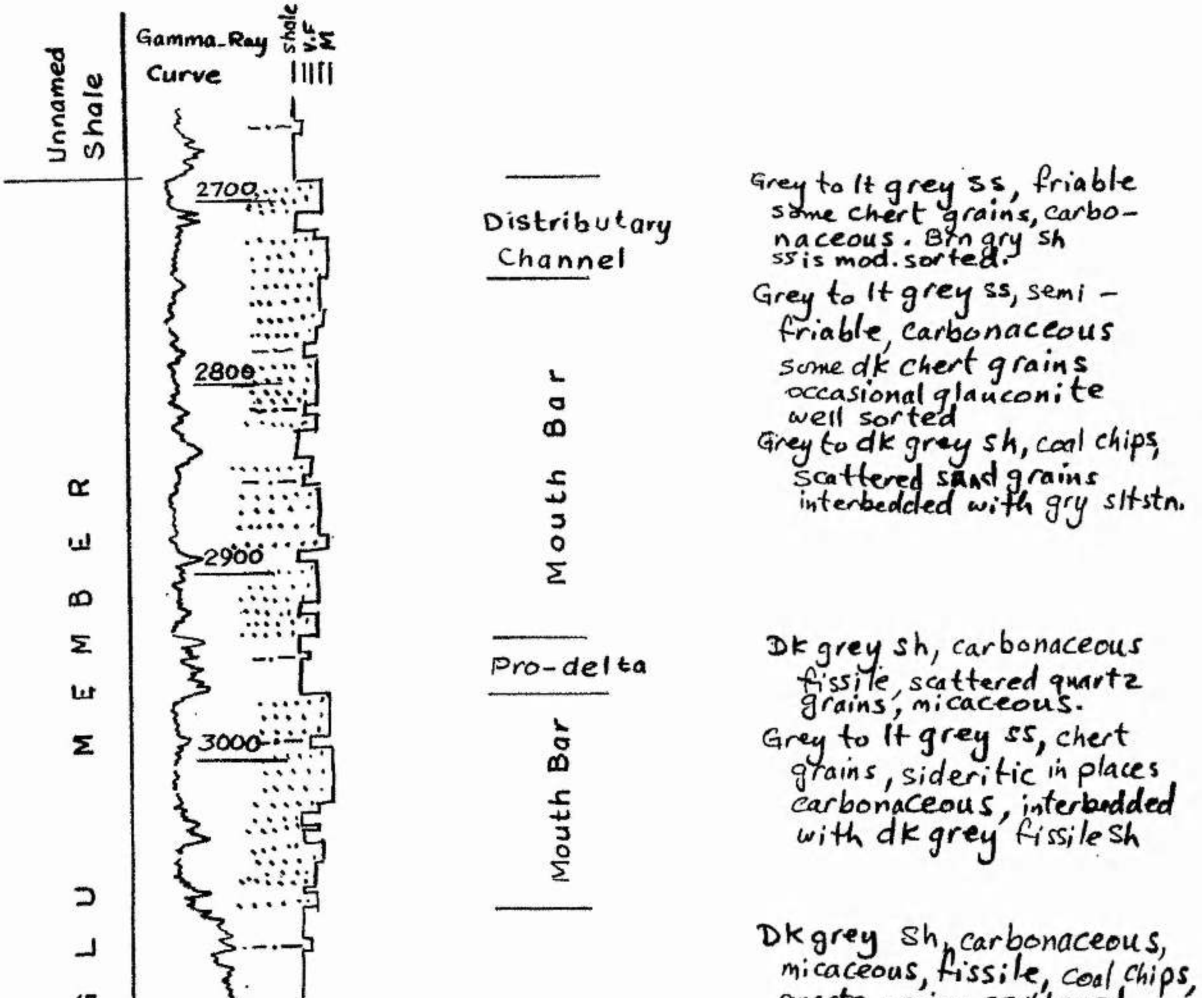
(for symbols see figure 20)



APPENDIX C

STRATIGRAPHIC SECTION F-36

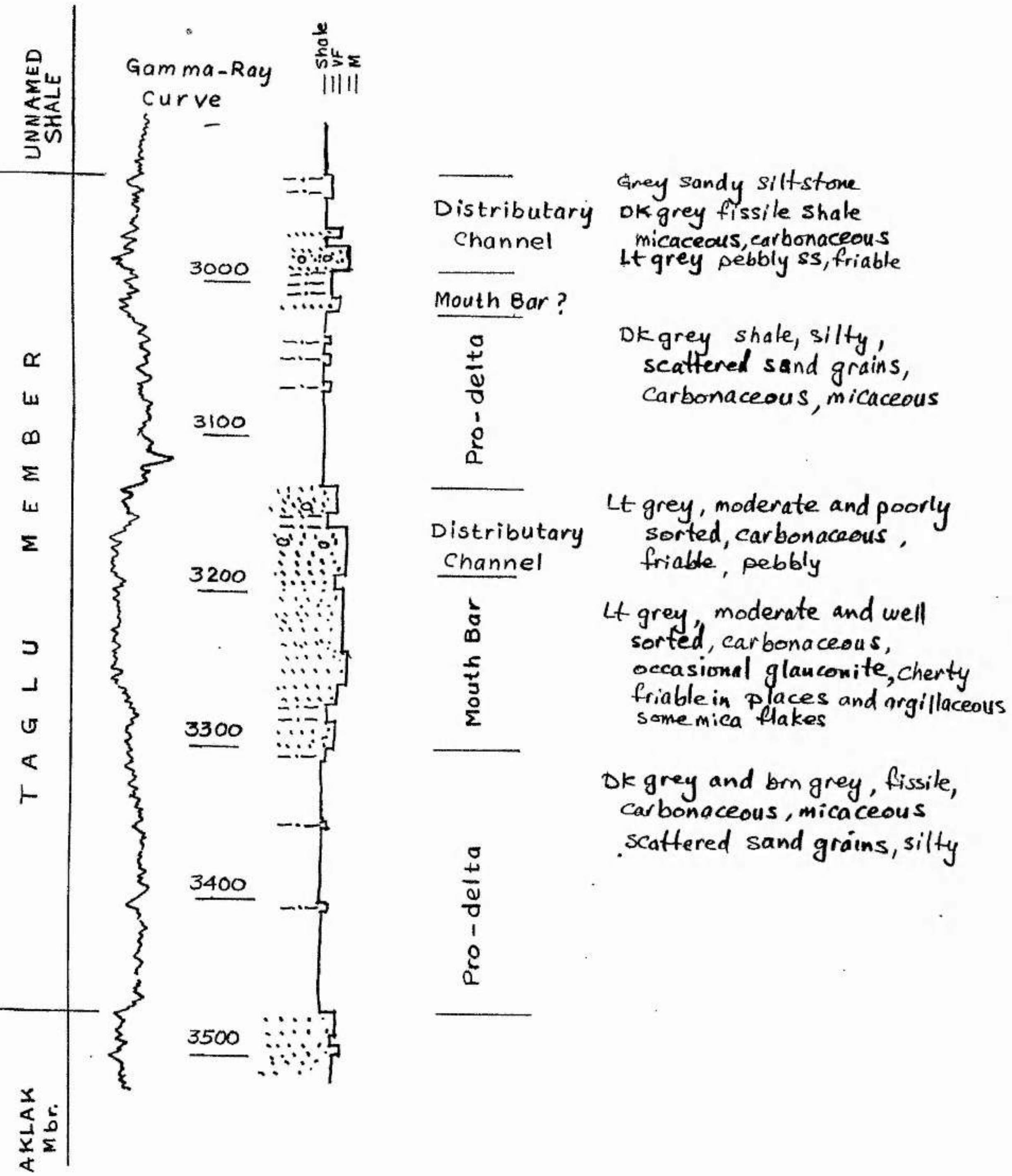
(for symbols see figure 20)



APPENDIX C

STRATIGRAPHIC SECTION H-30

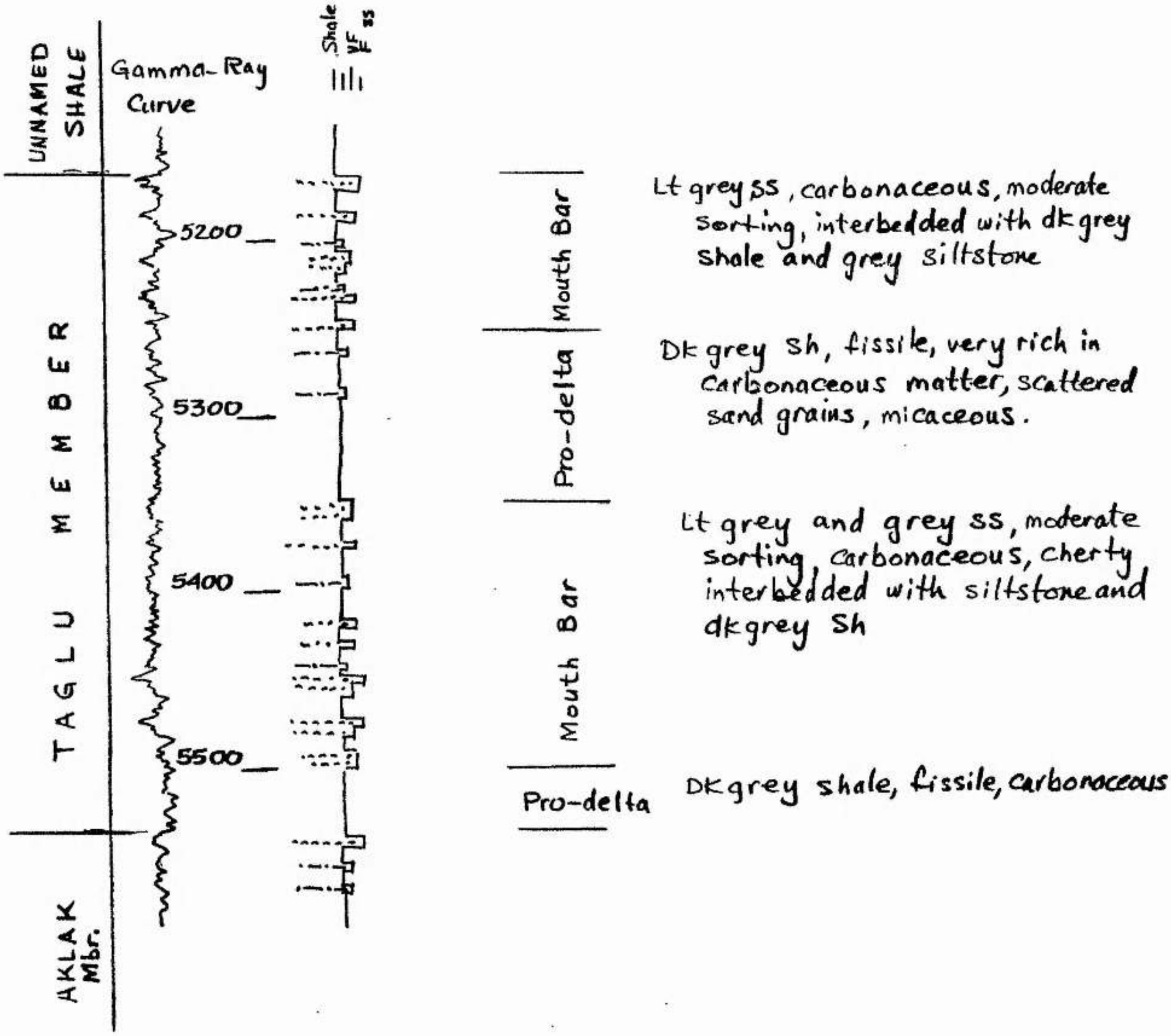
(for symbols see figure 20)



APPENDIX C

STRATIGRAPHIC SECTION A-06

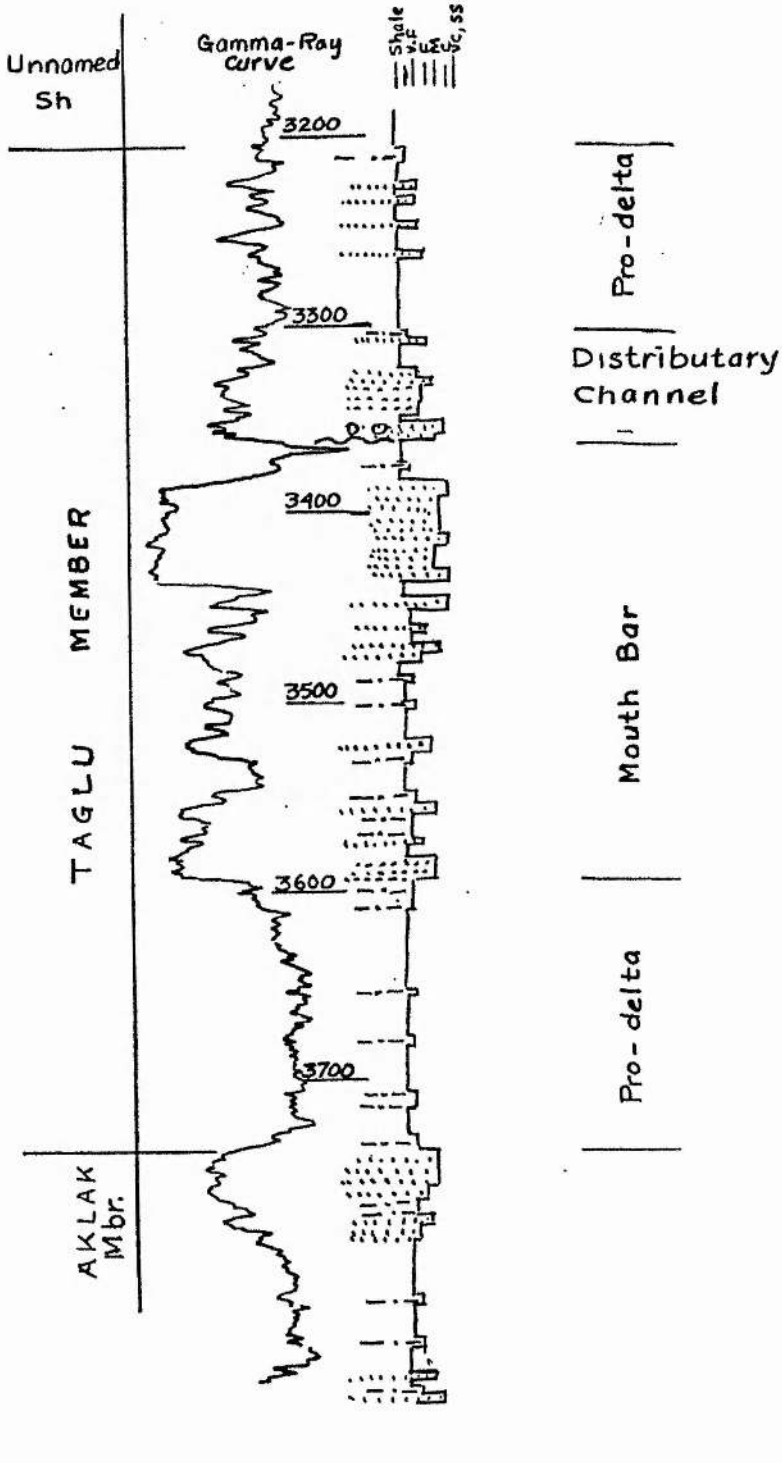
(for symbols see figure 20)



Appendix "C"

Stratigraphic Section C-21

(for symbols see figure 20)



Lt brn shale, silty, micaceous scattered sand grains, fissile interbedded with ss grey to lt grey, micaceous, carbonaceous.

Grey to lt grey, scattered chert grains, micaceous, a few pebbles carbonaceous

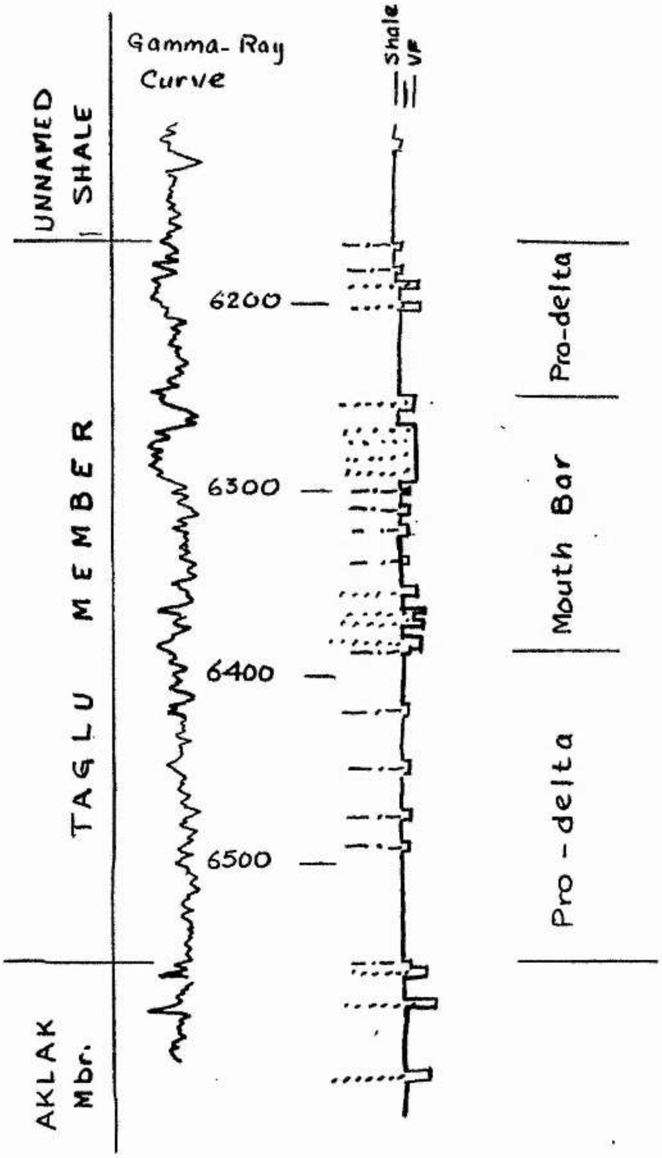
Lt grey to grey ss, friable scattered chert granules, micaceous and carbonaceous, some coal chips interbedded with grey siltstone which is micaceous, carbonaceous, sandy, and grey to dk grey sh which is fissile, micaceous, and carbonaceous.

Grey brn and dk grey shale, silty and sandy in places, micaceous, carbonaceous, fissile, interbedded with siltstone which is grey, sandy, micaceous, carbonaceous

APPENDIX C

STRATIGRAPHIC SECTION F-48

(for symbols see figure 20)



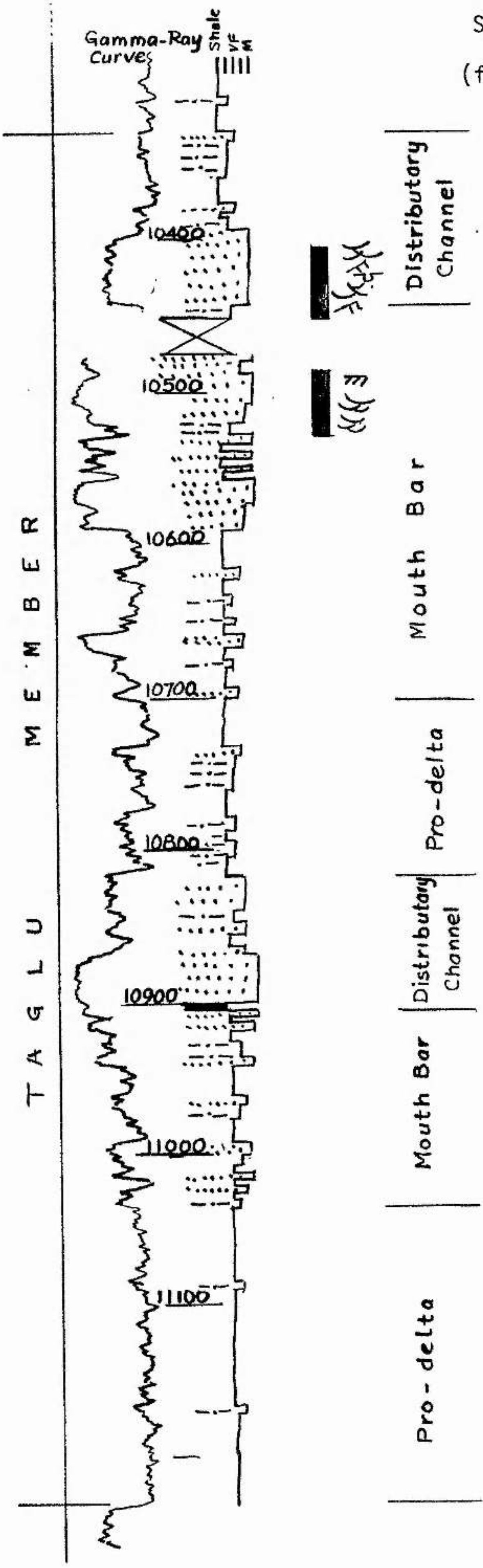
Grey and dk grey shale, fissile, Carbonaceous, micaceous, sandy and silty

Lt grey ss, cherty, occasional glauconite, carbonaceous, minor mica flakes. Interbedded with grey siltstone and dk grey shale. The ss is moderately sorted

Grey to dk grey shale, fissile, very rich in carbonaceous matter, contains mica flakes Sandy and silty throughout.

STRATIGRAPHIC SECTION D-55

(for symbols see figure 20)



Lt grey to grey siltsone, micaceous contains carbonaceous frags

Dk grey shale, fissile, carbonaceous micaceous

Grey to lt grey ss, minor siderite and glauconite, carbonaceous some coal chips, argillaceous, moderate sorting.

Grey brn, moderately sorted, coal chips, argillaceous, micaceous minor chert. Grey siltstone

Grey to dk grey sh, micaceous fissile and carbonaceous

Grey siltsone, carbonaceous and micaceous

Grey ss, silty, argillaceous, micaceous, some carb. frags.

Grey to dk grey sh, micaceous, carbonaceous, fissile

Grey siltstone, scattered ss grains, carbonaceous, micaceous.

Grey to lt grey ss, some siderite argillaceous, friable, coal chips and carbonaceous interbedded with siltstone similar to that described above

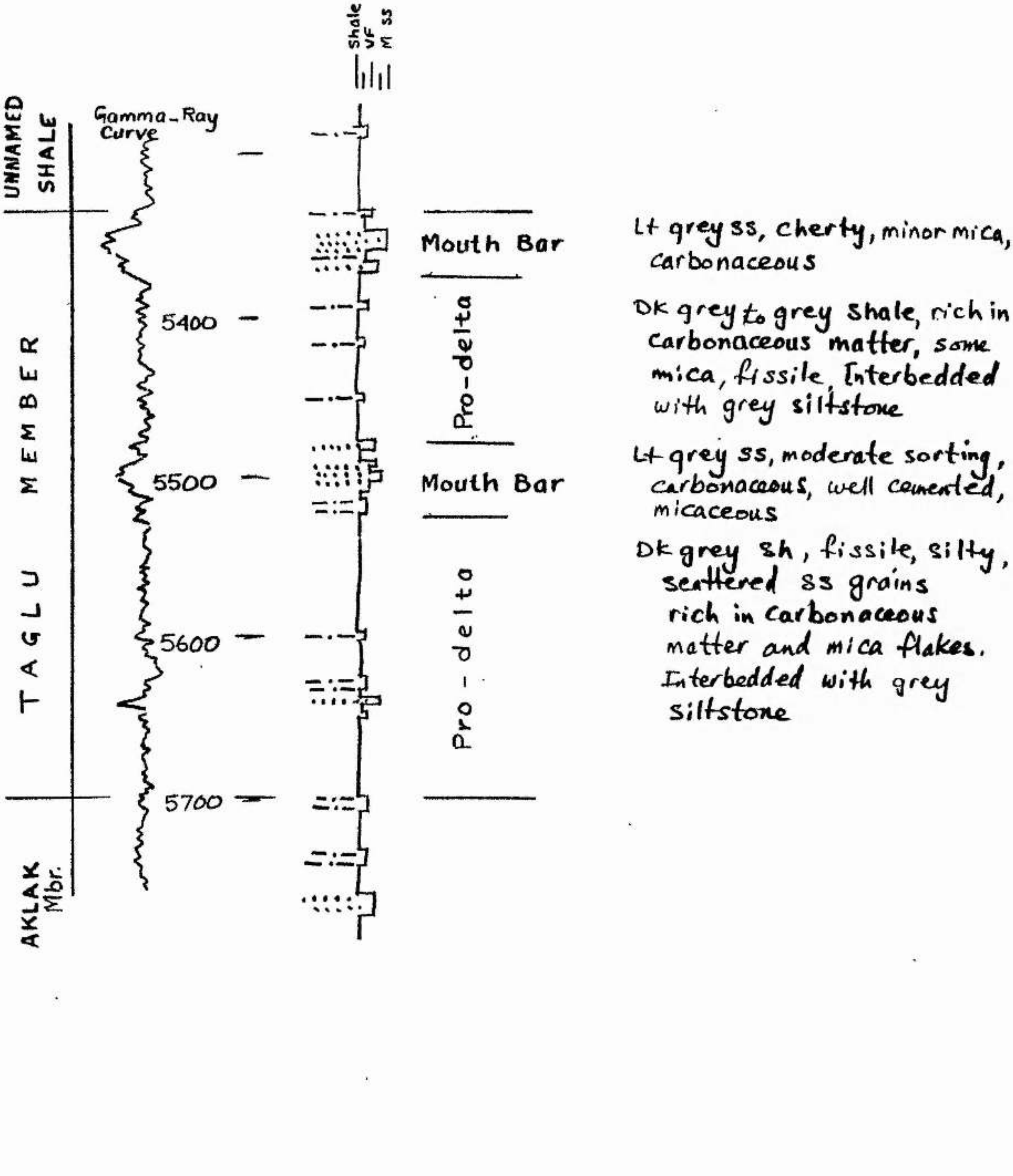
Grey to lt grey ss, argillaceous carbonaceous interbedded with siltstone and shale which both are micaceous and carbonaceous. ss is moderately sorted.

Grey to dk grey sh, fissile carbonaceous, micaceous, contains scattered ss and slt grains.

APPENDIX C

STRATIGRAPHIC SECTION J-37

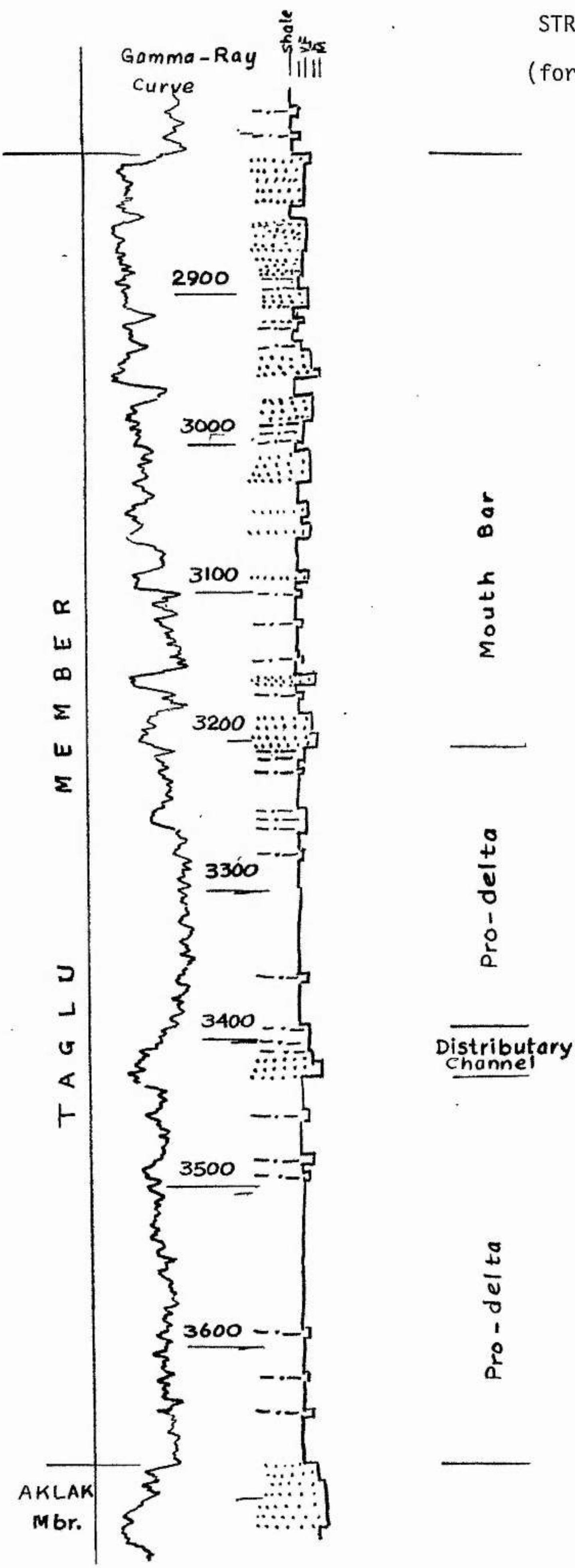
(for symbols see figure 20)



APPENDIX C

STRATIGRAPHIC SECTION O-54

(for symbols see figure 20)



Lt grey ss, argillaceous, friable moderate to well sorted, scattered chert granules and mica flakes, contains coal chips, carbonaceous. interbedded with dk grey shale, fissile, micaceous and grey siltstone, Occasional glauconite

Dk grey shale, carbonaceous micaceous, fissile interbedded with grey siltstone which is micaceous with scattered sand grains and carbonaceous matters.

Dk grey shale, carbonaceous, scattered sand grains, micaceous, silty, fissile, occasional coal chips and plant remains.

Lt grey ss, argillaceous, friable, micaceous, carbonaceous moderately sorted

Dk grey shale, carbonaceous, scattered sand grains, micaceous, silty, fissile, rich in plant remains and coal chips. Interbedded with grey siltstone, micaceous, carbonaceous

APPENDIX D

Distribution of cement in samples collected from the Taglu sandstone.

Borehole	Sample Depth or Range (ft)	Environment of Deposition	% Cement				
			Dolomite	Calcite	Siderite	Silica	Clay Minerals
O - 54	3040 - 50	Mouth Bar	4	17	3		3
	3400 - 10	Pro-delta	1		13		
	3640 - 50	Pro-delta	7	19			2
H - 30	3200 - 30	Mouth Bar	9	25			
	3290 - 3330	Mouth Bar	3	32			
	2980 - 3000	Distributary Ch.	2		3		
	3370 - 90	Pro-delta	3	1		1	
D - 55	10413	Distributary Ch.	2			7	
	10437	Distributary Ch.	2			4	1
	10515	Mouth Bar	9		4	4	5
	10700 – 800	Mouth Bar/Pro-dta.	4	1		3	
	10800 – 850	Distributary Ch.	4		3	2	
	10850 – 900	Distributary Ch.	4		2	4	
	11200 – 300	Pro-delta	2	1	4		1
G - 33	8154	Distributary Ch.	4		1	1	3
	8399	Distributary Ch.			1		14
	8453	Distributary Ch.	2		1		7
	8511	Mouth Bar			4		6
	8227	Distributary Ch.	6		3		3
	8170	Distributary Ch.	4	1	1	1	
	8205	Distributary Ch.	1		1	2	1
	8264	Mouth Bar	2				2
	10600 – 700	Pro-delta	4		1	6	
D - 27	3600 – 700	Distributary Ch.	8	1			6
	3700 – 800	Distributary Ch.	21	12	2		
	3800 – 850	Distributary Ch.	26	9	1		
	3850 – 900	Splay	18	5			
	3900 – 4000	Splay	20	1	4		1
	4000 – 100	Distributary Ch. and Splay	9	10	2		
	4100 – 200	Distributary Ch. and Splay	5	15	7		
C - 42	9418	Distributary Ch.	5		1	2	1
	9400 – 50	Distributary Ch.	10	3	1	2	
	9450 – 500	Mouth Bar	7	7	4	1	
	9536	Mouth Bar	3		1		1
	9650 – 9700	Distributary Ch.	5		2	2	1

Borehole	Sample Depth or Range (ft)	Environment of Deposition	% Cement Dolomite	Calcite	Siderite	Silica	Clay Minerals
C - 42	9691	Distributary Ch.	5		6	2	2
	9699	Distributary Ch.	3		4	4	1
	9758	Mouth Bar	7			3	3
	9900 - 10000	Pro-delta	2	1	9	2	1
P - 53	5000 - 100	Marine	5		2		1
	5100 - 200	Marine	23	4	2		
	5200 - 300	Mouth Bar	15	2	1	1	
	5300 - 5400	Distributary Ch.	5		5		2
	5400 - 500	Mouth Bar	3		2		
F - 28	3600 - 700	Mouth Bar	16	2	2		4
	3700 - 800	Pro-delta	3				5
E - 29	4330	Mouth Bar	7	17	2		1
	4020 - 30	Mouth Bar	4	19			1
	4230 - 40	Splay	8	7	6		4
	3920 - 40	Distributary Ch.	1	2	4		1
I - 22	1570	Mouth Bar	9	19	1		1
	1420	Distributary Ch.	2				
	1450	Distributary Ch.	7	25	1		1
O - 14	1470 - 80	Distributary Ch.	8	20	1		4
	1700 - 800	Mouth Bar	12	1	1		2
	1802	Mouth Bar	2			1	1
	1800 - 50	Mouth Bar	4		1		1

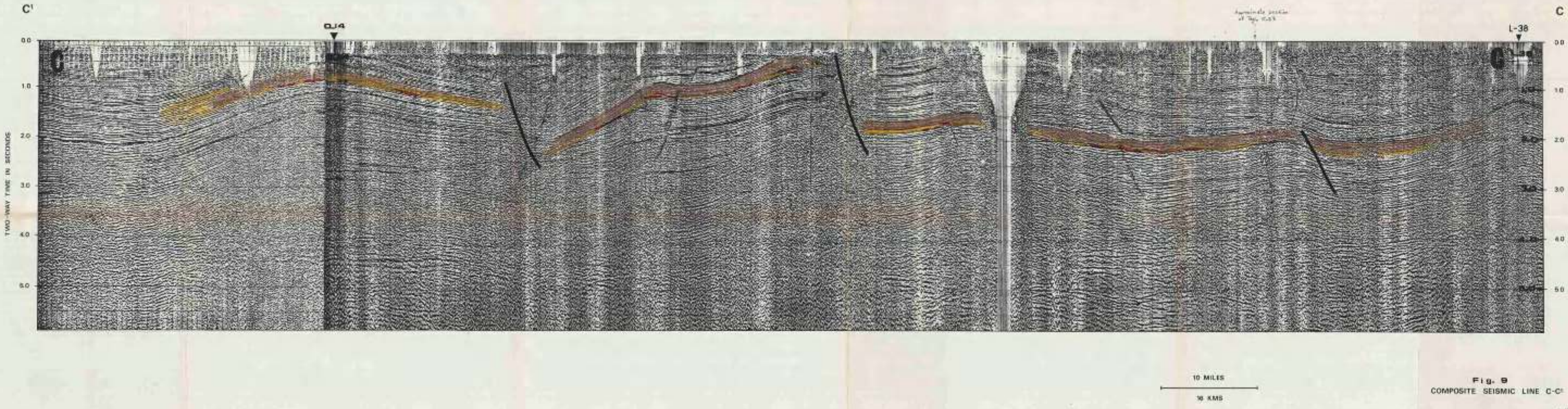
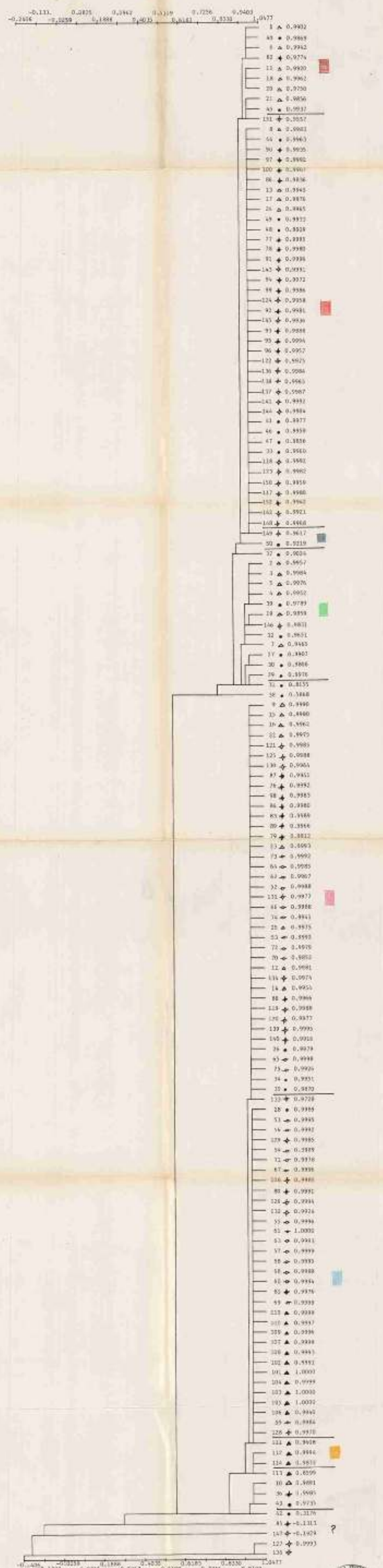
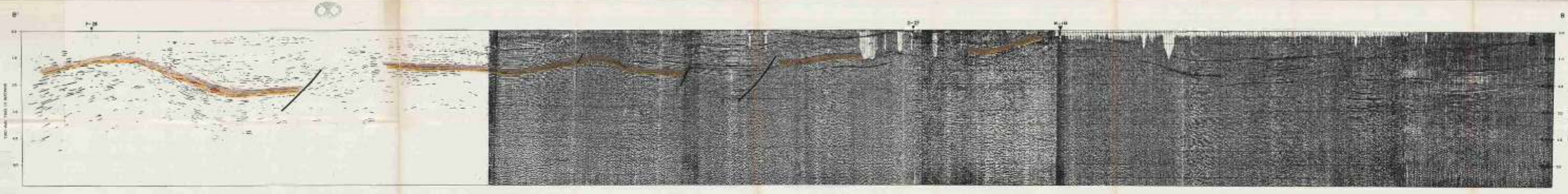


Fig. 9
COMPOSITE SEISMIC LINE C-C'

Figure 15. Cluster analysis diagram. Values along x-axis are similarity level of clustering. All samples from any borehole are represented by one symbol shown next to sample number.

Legend: F-53 △ , G-33 ● , E-29 ◈ , H-30 ✚ , O-14 ▲ , I-22 ✧ .





COMPOSITE SEISMIC LINE B-B'